ANNUAL REPORT

OF THE

BOARD OF REGENTS

OF THE

SMITHSONIAN INSTITUTION

SHOWING

THE OPERATIONS, EXPENDITURES, AND CONDITION
OF THE INSTITUTION

TO

JULY, 1896.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1898.

LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

ACCOMPANYING

The annual report of the Board of Regents of the Institution for the year ending June 30, 1896.

SMITHSONIAN INSTITUTION,
Washington, D. C., July 1, 1896.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1896.

I have the honor to be, very respectfully, your obedient servant,

S. P. LANGLEY,
Secretary of Smithsonian Institution.

Hon. ADLAI E. STEVENSON,
President of the Senate.

ANNUAL REPORT OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1896.

SUBJECTS.

1. Proceedings of the Board of Regents for the session of January, 1896.

2. Report of the Executive Committee, exhibiting the financial affairs of the Institution, including a statement of the Smithson fund, and receipts and expenditures for the year ending June 30, 1896.

3. Annual report of the Secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1896, with statistics of exchanges, etc.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1896.

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THE SMITHSONIAN INSTITUTION.

MEMBERS EX OFFICIO OF THE "ESTABLISHMENT."

GROVER CLEVELAND, President of the United States.
ADLAI E. STEVENSON, Vice-President of the United States.
MELVILLE W. FULLER, Chief Justice of the United States.
RICHARD OLNEY, Secretary of State.
JOHN G. CARLISLE, Secretary of the Treasury.
DANIEL S. LAMONT, Secretary of War.
JUDSON HARMON, Attorney-General.
WILLIAM L. WILSON, Postmaster-General.
HILARY A. HERBERT, Secretary of the Navy.
HOKE SMITH, Secretary of the Interior.
J. STERLING MORTON, Secretary of Agriculture.

REGENTS OF THE INSTITUTION.

(List given on the following page.)

OFFICERS OF THE INSTITUTION.

SAMUEL P. LANGLEY, *Secretary,*

Director of the Institution and of the U. S. National Museum.

G. BROWN GOODE, *Assistant Secretary.*

REGENTS OF THE SMITHSONIAN INSTITUTION.

By the organizing act approved August 10, 1846 (Revised Statutes, Title LXXIII, section 5580), and amended March 12, 1894, "The business of the institution shall be conducted at the city of Washington by a Board of Regents, named the Regents of the Smithsonian Institution, to be composed of the Vice-President, the Chief Justice of the United States, three members of the Senate, and three members of the House of Representatives, together with six other persons, other than Members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of the same State."

REGENTS FOR THE YEAR ENDING JUNE 30, 1896.

The Chief Justice of the United States:
MELVILLE W. FULLER, elected Chancellor and President of the Board January 9, 1889.

The Vice-President of the United States:
ADLAI E. STEVENSON.

	Term expires.
United States Senators:	
JUSTIN S. MORRILL (appointed Feb. 21, 1883, Mar. 23, 1885, and Dec. 15, 1891)	Mar. 3, 1897
SHELBY M. CULLOM (appointed Mar. 23, 1885, Mar. 28, 1889, and Dec. 18, 1895)	Mar. 3, 1901
GEORGE GRAY (appointed Dec. 20, 1892, and Mar. 20, 1893)	Mar. 3, 1899
Members of the House of Representatives:	
JOSEPH WHEELER (appointed Jan. 10, 1888, Jan. 6, 1890, Jan. 15, 1892, Jan. 4, 1894, and Dec. 20, 1895)	Dec. 22, 1897
ROBERT R. HITT (appointed Aug. 11, 1893, Jan. 4, 1894, and Dec. 20, 1895)	Dec. 22, 1897
ROBERT ADAMS, Jr. (appointed Dec. 20, 1895)	Dec. 22, 1897
Citizens of a State:	
JAMES B. ANGELL, of Michigan (appointed Jan. 19, 1887, and Jan. 9, 1893)	Jan. 19, 1899
ANDREW D. WHITE, of New York (appointed Feb. 15, 1888, and Mar. 19, 1894)	Mar. 19, 1900
WILLIAM PRESTON JOHNSTON, of Louisiana (appointed Jan. 26, 1892)	Jan. 26, 1898
Citizens of Washington:	
JOHN B. HENDERSON (appointed Jan. 26, 1892)	Jan. 26, 1898
GARDINER G. HUBBARD (appointed Feb. 27, 1895)	Feb. 27, 1901
WILLIAM L. WILSON (appointed Jan. 14, 1896)	Jan. 14, 1902

Executive Committee of the Board of Regents.

J. B. HENDERSON, *Chairman*. WILLIAM L. WILSON. GARDINER G. HUBBARD.

JOURNAL OF PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION.

ANNUAL MEETING OF THE BOARD OF REGENTS.

JANUARY 22, 1896.

In accordance with a resolution of the Board of Regents, adopted January 8, 1890, by which its stated annual meeting occurs on the fourth Wednesday of January, the board met to-day at 10 o'clock a. m.

Present: The Chancellor (the Hon. M. W. Fuller) in the chair; the Vice-President of the United States (the Hon. A. E. Stevenson), the Hon. J. S. Morrill, the Hon. S. M. Cullom, the Hon. George Gray, the Hon. Joseph Wheeler, the Hon. R. R. Hitt, the Hon. Robert Adams, jr., the Hon. Andrew D. White, the Hon. J. B. Henderson, the Hon. Gardiner G. Hubbard, the Hon. W. L. Wilson, and the Secretary Mr. S. P. Langley.

Excuses for nonattendance were read from Dr. William Preston Johnston, on account of illness, and from Dr. J. B. Angell, on account of an important business engagement.

At the Chancellor's suggestion, the Secretary read the minutes of the last meeting, in abstract. There being no objection, the minutes stood approved.

The Secretary then announced the following reappointments and appointments of Regents:

REAPPOINTMENTS.

The Hon. S. M. Cullom, of Illinois, by the President of the Senate, on December 18, 1895.

The Hon. Joseph Wheeler, of Alabama, and the Hon. R. R. Hitt, of Illinois, by the Speaker of the House of Representatives, on December 20, 1895.

The Hon. William L. Wilson, of West Virginia, by joint resolution of Congress, approved by the President January 14, 1896.

APPOINTMENTS.

The Hon. Gardiner G. Hubbard, of Washington, D. C., by joint resolution of Congress, approved by the President February 27, 1895.

The Hon. Robert Adams, jr., of Pennsylvania, by the Speaker of the House of Representatives, on December 20, 1895.

The Chancellor announced that the vacancies existing in the Executive Committee were customarily filled by the adoption of resolutions, and General Wheeler introduced the following:

Resolved, That the vacancies in the Executive Committee be filled by the election of the Hon. William L. Wilson and the Hon. Gardiner G. Hubbard.

Resolved, That the Hon. J. B. Henderson be elected chairman of the Executive Committee.

On motion, the resolutions were adopted.

The Chancellor announced the death of Dr. Henry Coppée, and appointed Senator Henderson and the Secretary a committee to draft suitable resolutions. Senator Henderson, on behalf of the committee, presented the following:

Whereas the members of the Board of Regents of the Smithsonian Institution are called to mourn the death of their colleague, the late Henry Coppée, LL. D., acting president of Lehigh University, for twenty years a Regent of the Institution, and long a member of its Executive Committee:

Resolved, That the Board of Regents feels sincere sorrow in the loss of one whose distinguished career as a soldier, a man of letters, and whose services in the promotion of education command their highest respect and admiration.

Resolved, That in the death of Dr. Coppée the Smithsonian Institution and the Board of Regents have suffered the loss of a tried and valued friend, a wise and prudent counsellor, whose genial courtesy, well-stored, disciplined mind, and sincere devotion to the interests of the Institution will be ever remembered.

Resolved, That these resolutions be recorded in the journal of the proceedings of the board, and that the Secretary be requested to send a copy to the family of their departed associate and friend in token of sympathy in this common affliction.

On motion, the resolutions were unanimously adopted by a rising vote.

The Secretary presented his annual report for the fiscal year ending June 30, 1895, and said: "I may speak of the last year as one of varied and fruitful activities, which are detailed in this report, which, however, does not cover some points I desire presently to bring before the Regents."

After discussion by the Regents of a report upon the condition of the Avery fund, the Secretary said: "I may ask the attention of the Regents to the fact that the Hodgkins fund prizes have been awarded, one of which—the principal one, of $10,000—was given through the American embassy in London to Lord Rayleigh and Professor Ramsay for the discovery of a new element in the atmosphere 'Argon.' A similar prize of 50,000 francs was given nearly simultaneously to the same persons by the Institute of France. The second prize was not awarded, and the third (of $1,000) was given to M. Varigny for the best popular treatise, in accordance with the terms of the announcement. Morever, three silver and six bronze medals have been awarded to the laureates out of nearly two hundred contestants. Letters had been sent to these, with the thanks of the Institution, and inviting them to say whether they would have their memoirs remain here or be sent back. In certain cases, in accordance with the suggestion made last year by General

Wheeler, preparations had been made for the publication of some of the more meritorious ones. Some of them exhibited such care and pains in the preparation that it was thought desirable to give some kind of token of the appreciation of the Institution, and medals of silver and bronze had been awarded. These medals (of which the Secretary showed a photograph) were now being struck."

Mr. Wheeler inquired if it was the papers that had received honorable mention which it was proposed to print, to which the Secretary responded that that was the purpose, save where the authors preferred to print themselves.

The Secretary went on to say:

There has probably been no single event in the history of the Institution which has drawn more attention to it abroad than the announcement and award of these prizes, which the Regents will remember were given in accordance with the expressed desire of the donor that such might be at any rate the first disposition of the income of the amount especially set apart by him for the study of the atmosphere. Having done this, I feel that a sort of pious duty has been accomplished in fulfilling the wishes of Mr. Hodgkins, but while the money has been well bestowed for once in drawing the almost universal attention of the scientific world to the Hodgkins bequest and to the Institution and the fund which it administers, as well as to its fitness as an administrator of other trusts of this character, it may be doubted if it is a wise policy to continue the giving of such large prizes, which have rarely been found efficacious in stimulating discovery. Unless, therefore, I am instructed by the Regents to do otherwise, the income hereafter will be spent in the customary channels of the Institution's activities, through the aid of investigations in regard to the air which more immediately promote the general welfare.

The large amount required for the great prize to which I have alluded, and which is not likely to be called for again, has, of course, naturally limited the application of this fund to the aid of original research in more practical ways, which I hope it will take hereafter; but I may mention one outcome of it, a valuable investigation by Dr. Weir Mitchell and Dr. Billings in "The composition of expired air."

Continuing, the Secretary said:

I now desire to bring before the Regents a matter in which they may see fit to express some opinion.

The fundamental act creating the Institution, in enumerating its functions, apparently considers it first as a kind of Gallery of Art, and declares that all objects of *art* and of foreign and curious research, the property of the United States, shall be delivered to the Regents, and only after this adds that objects of natural history shall be so also.

The scientific side of the Institution's activities has been in the past so much greater than its æsthetic that it is well to recall the undoubted fact that it was intended by Congress to be a curator of the national art, and that this function has never been forgotten, though often in abeyance.

In 1849, your first Secretary, Joseph Henry, in pursuance of this function of an Institution which, in his own words, existed for "the true, the beautiful, as well as for the immediately practical," purchased of the Hon. George P. Marsh a collection of works of art—chiefly engravings—for the sum of \$3,000, understood then to be but a fraction of its cost, and which, owing to the great rise in the market value of such things in the last fifty years, does not in the least represent its value to-day. It is impossible to state what the present value of the collection is, without an examination of the engravings and etchings, but experts that I have consulted say that the rise in all good specimens of engraving and etching during the forty-seven

years which have elapsed since the purchase has been so great that if these had then the value attributed to them they must be worth from five to ten times that amount now, or even more.

Immediately after the fire at the Institution, in 1865, doubt was felt that the building was a place of safety, and a portion of the collection was transferred to the Library of Congress, and in 1874 and 1879 other portions were lent to the newly founded Corcoran Art Gallery. The transfer was with the express understanding that they were there for deposit only, and to be reclaimed by the Regents at any time.

A portion of the collection is identified by Mr. Spofford as in the charge of the Library at the Capitol, except a few volumes and engravings which he hopes to find at the time of the coming transfer to the new building. There is no question made by the Corcoran Gallery about the fact of the engravings and etchings which they have on deposit.

In view of the fact of the coming occupancy of the new Congressional Library, in which it is expected that special quarters will be assigned to the Smithsonian deposit, both for storing in the "East Stack" of its now over 300,000 titles, and of a suitable room for their consultation, and of the further fact that the Corcoran Gallery will also shortly move into a new building, I have thought it might be desirable for the Regents to take action looking to the reclamation of the engravings, etchings, and other works of art.

This building has since been made fireproof, and recent changes have given it means of properly caring for these collections.

Senator Gray offered the following resolution, which was adopted:

Resolved, That the question of the propriety of bringing the works of art belonging to the Institution under the more immediate control of the Board of Regents be referred to the Executive Committee and the Secretary, with power to act.

The Secretary proceeded:

The charter of the Smithsonian Institution bears the date of August 10, 1846. For some years the question has been under consideration how best to celebrate the completion of the first half century, and the matter was fully discussed in 1893 with the Executive Committee. It seems quite impracticable to arrange for a gathering of delegates from other scientific institutions, such as are often held on similar occasions by universities and academies of science. The simplest and most effective means seems to be the publication of a suitable memorial volume, which should give an account of the origin of the Institution, its achievements, and its present condition.

Arrangements have been made, therefore, for the preparation of such a volume, and the work is in an advanced state. The editorial supervision has been intrusted to the Assistant Secretary, and a number of persons, eminent authorities in their own specialties, have been invited to contribute special chapters.

SMITHSON MEMORIAL TABLETS.

Continuing, the Secretary said:

In the same connection, I have, under the authority of the Regents, directed two suitable bronze tablets to be set up at the burial place of Smithson, in Genoa—one in the English Church and the other on his tomb.

SMITHSONIAN TABLE AT NAPLES.

The Secretary spoke of the Zoological Station at Naples, in connection with the Tables supported by foreign governments, and stated that on the petition of American universities and scholars he had

paid, in 1893, $1,500 for the use of such a Table for three years, the subscription expiring during the present year. He showed a petition signed by the leading naturalists of the country asking that the Table be continued. It had been the means of bringing the Institution into closer relationship with colleges and universities throughout the country, and he was favorably inclined to the action. It was mentioned now, not as needing any additional sanction from the Regents, but to recall a matter of some possible interest to them, as the Institution stood in this case in the same position as that occupied abroad by the governments of such countries as Germany and Italy.

THE NATIONAL MUSEUM.

The Secretary resumed:

I do not think I have occasion to speak at length to the Regents about the interests of the different Government bureaus under their care, further than I have so fully done in the report, but in regard to the need of larger quarters for the Museum, and the dangerous character of the sheds used for storage purposes immediately under the windows of the Smithsonian building, I ask the particular attention of the Regents to the significant statement on page 5 of the report that no insurance company will undertake to insure these shops, the property of the Institution, at less than ten times the ordinary rate. They are under our walls, almost in contact with them, and are a constant menace.

The Secretary added:

The complete remedy is to build the necessary quarters, but a partial remedy is for Congress to give authority to lease warehouses in the vicinity for storage. The present ones are choked with matter largely inflammable, and the condition can hardly be worse or more dangerous than it is.

Many valuable gifts have been received during the year. A considerable number of important scientific memoirs have been published, and many more are in preparation. More money and room are urgently needed, and the lack of these prevents the proper utilization of the national collections.

Of the Bureau of Ethnology, I need only say that it has proceeded in its ordinary path of usefulness under the efficient direction of Major Powell. I have myself, however, used a certain unexpended balance in sending out an expedition under the charge of Dr. J. Walter Fewkes, which resulted in the exploration of a very interesting ruin near the town of Moqui, the remains of a town which was destroyed by hostile Indians before the first visit of the Spaniards. This is the first careful exploration of a thoroughly pre-Columbian town site, and the collections obtained throw much new light upon the customs of these ancient peoples. The collections, it may be added, are of great intrinsic value, since the pottery is the finest that has ever yet been exhumed, and the series obtained being monographic for a special locality, is unequaled by any other of the kind in the world.

I have also authorized another expedition to investigate the Seri Indians, which has been lately conducted to a successful issue by Mr. McGee.

THE BUREAU OF INTERNATIONAL EXCHANGES.

The Secretary continued:

The Smithsonian numbers in the records of its Exchange Bureau about 24,000 correspondents, scattered over the entire world.

The appropriation for the service is $17,000, and in addition an average of about $3,000 a year has been received from Government bureaus and others for transporta-

tion of the exchanges. The service is not altogether satisfactory for lack of funds to insure fast transportation. Reports and publications that should go promptly are now compelled to wait because they are free freight. Nearly fifty years ago some of the lines gave the Institution free transportation in the interest of "the diffusion of knowledge." This was once well enough, but the result now is that Government publications, which were not contemplated in the original gift, have to wait till there is room which can not be used for paid freight. It is doubtful economy.

The United States Government, by treaty made at Brussels in 1886 and proclaimed by the President in 1889, is under obligation to maintain an exchange bureau. A treaty was also made at the same time for the immediate exchange of the parliamentary proceedings of the countries concerned. For this no appropriation has been made, though an estimate of the appropriation needed for the purpose, submitted by me to the honorable the Secretary of State at his request, has been transmitted by him in due form to Congress for action.

NATIONAL ZOOLOGICAL PARK.

Proceeding, the Secretary said:

The park under the charge of the Regents is undoubtedly the finest natural site for such a purpose in the immediate vicinity of any large capital, not only of this country, but of Europe and the world. But comparatively little can be done under an appropriation which is barely sufficient to police the park and keep alive and safely house the animals there, without buying any new ones.

The Regents will remember that the park was intended originally for a national rather than for a local purpose, and that the prominent feature of it was to be the preservation of our native fauna from extinction. I want to ask the attention of the Regents, and especially of those who can influence legislation in Congress, to a paragraph in the report, on page 30, which, it seems to me, ought to be known to Congress, and to call out some measure to relieve this threatened extinction. It is popularly supposed that the remnant of the great body of bison which once covered this continent is in safety in the Yellowstone Park, under Government control, but the herd there is being so rapidly depleted that unless some measures are taken it is doubtful if any will be left at the end of the present year. There is a stockade there, put up at the expense of the Zoological Park appropriation, to hold those to be sent to Washington preparatory to their transportation. None have yet occupied it; but I think that unless the bison are transferred to this or to the Zoological Park here, which has sufficient space for all that are left, the final extinction of all under Government control, except the few already here, may be looked for in a few months more.

The Secretary here read the letter of Captain Anderson, the Superintendent of the Yellowstone Park, as follows:

DECEMBER 12, 1895.

I can give you no definite information about the bison in the Hayden Valley, near your corral. My scouting parties have reported the trails of several small bands leading in that direction, but as the snowfall has been light they have not as yet been driven to that narrow area. I do not expect to be able to get an accurate estimate of their number before the latter part of January. I hope there are enough remaining for a source of supply for your park, and if they can be inclosed the cost of maintenance will be very small.

The reports made through the newspapers of the slaughter of the bison recently are, of course, much exaggerated, but, unfortunately, several have been killed. I feel pretty certain that ten were killed within the past four months. I have now in custody in the guardhouse a man who was captured in possession of the scalps of five.

I made a pretty thorough tour of their range in October last, and saw very few signs. I am sure that I have heretofore overestimated their numbers. *I doubt if there are over fifty remaining*, and these will not all winter in the Hayden Valley. They increase but slowly under the best conditions, and here, where they are being *constantly pursued* and where the winters are very severe, but small increase can be looked for. Of course the stockade recently erected will be a great assistance in their protection, if they can be secured within it.

All of the animals in the park are protected properly and are increasing, *with the exception of the bison*, and of these it is difficult to predict as yet.

The Secretary resumed:

The park here is, however, fulfilling its functions as "the lungs of the city" and for the "instruction and recreation of the people," and no better evidence is needed to corroborate this than the crowds which constantly visit it.

ASTROPHYSICAL OBSERVATORY.

Concerning the Astrophysical Observatory, the Secretary said:

The Regents will remember that five years ago it was resolved: "That if an appropriation should be made by Congress for the maintenance of an 'astrophysical observatory,' under the direction of the Smithsonian Institution, the Regents will expend for this purpose, from moneys already donated to them, $10,000 for the construction of buildings for said observatory, whenever a suitable site shall be designated by Congress and obtained for the purpose." * * *

It was then anticipated that the first step to be taken by Congress in the matter would be the provision of a suitable site. Congress, however, saw fit to make the appropriation in terms which provided for the scientific work of an observatory already in progress, and in order to utilize this appropriation, which would otherwise have had to be returned to the Treasury, the temporary and inadequate quarters in the sheds immediately behind the Smithsonian building were provided in 1890.

I have had too much personal concern with the work which has been done there not to perhaps speak of it with a friendly bias, but if I may believe the expressions of men of science competent in this matter, hardly any more important work in the spectrum has been done in the century than has been going on and is still going on here under the Smithsonian Institution, though under such disadvantageous conditions.

Briefly, this research is giving us a knowledge of nearly thrice the amount of the details of the solar energy that were known to Sir Isaac Newton, and in a region which remained almost untouched since he left it until our own day, when these researches took it up.

As has been stated in previous reports, there is an element of uncertainty in the results, due to the fact that they are all obtained through an excessively delicate instrument which registers minute vibrations set up by the sun, but which also registers (whether we will or no) vibrations coming from local causes, such as the tremor of the ground, which always exists, however imperceptible to the ordinary sense, in the midst of a great city. There are ways of discriminating between these true and false effects, but the latter can hardly be eliminated—certainly not in very many years of labor—in the present altogether unfit site, whereas the work already sketched out could be pushed to successful conclusion and publication in a single twelvemonth in a quiet locality.

In view of the delay in providing a site for a building, the Secretary has already been authorized by a subsequent resolution of the Regents to expend the sum of $10,000 bequeathed by J. H. Kidder and given by Alexander Graham Bell "in directions consonant with the known wishes of the testator and the donor," but little of it has been used; and unless some remedy is found against the tremor incident to this bad

site, it is contemplated to expend it during the coming year in a new installation, in case a suitable site can be obtained by Congressional action, such as on the old Naval Observatory grounds, or otherwise. The expenditure of this relatively small sum will, it is hoped, provide the requisite indispensable buildings, which will be of a very modest character.

On motion, the Secretary's report was accepted.

At the Chancellor's suggestion, it was moved and carried—

That the recommendations in the Secretary's report be referred to the Executive Committee, with power to act.

Senator Henderson presented the report of the Executive Committee for the year ending June 30, 1895.

On motion, the report was adopted.

Senator Henderson introduced the following customary resolution relative to income and expenditure:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1897, be appropriated for the service of the Institution, to be expended by the Secretary, with the advice of the Executive Committee, with full discretion on the part of the Secretary as to items.

On motion, the resolution was adopted.

The Secretary then read letters—

From the master of Pembroke (Smithson's College), Oxford, thanking the Institution for a set of its publications and asking for a portrait of Smithson.

From the Royal Institution of Great Britain, returning thanks for a portrait of Mr. Hodgkins.

From Mrs. J. C. Welling, for a copy of the resolutions passed by the board on the death of Dr. Welling.

There being no further business to come before the board, on motion it adjourned.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDING JUNE 30, 1896.

To the Board of Regents of the Smithsonian Institution:

Your Executive Committee respectfully submits the following report in relation to the funds of the Institution, the appropriations by Congress, and the receipts and expenditures for the Smithsonian Institution, the United States National Museum, the International Exchanges, the Bureau of Ethnology, the National Zoological Park, and the Astro-Physical Observatory for the year ending June 30, 1896, and balances of former years:

SMITHSONIAN INSTITUTION.

Condition of the Fund July 1, 1896.

The amount of the bequest of James Smithson deposited in the Treasury of the United States, according to act of Congress of August 10, 1846, was $515,169. To this was added by authority of Congress, February 8, 1867, the residuary legacy of Smithson and savings from income and other sources to the amount of $134,831.

To this also have been added a bequest from James Hamilton, of Pennsylvania, of $1,000; a bequest of Dr. Simeon Habel, of New York, of $500; the proceeds of the sale of Virginia bonds, $51,500; a gift from Thomas G. Hodgkins, of New York, of $200,000 and $8,000, being a portion of the residuary legacy of Thomas G. Hodgkins, and $1,000, the accumulated interest on the Hamilton bequest, making in all, as the permanent fund, $912,000.

The Institution also holds the additional sum of $42,000, received upon the death of Thomas G. Hodgkins, in registered West Shore Railroad 4 per cent bonds, which were, by order of this committee, under date of May 18, 1894, placed in the hands of the Secretary of the Institution, to be held by him subject to the conditions of said order.

Statement of the receipts and expenditures from July 1, 1895, to June 30, 1896.

RECEIPTS.

Cash on hand July 1, 1895		$63,001.74	
Interest on fund July 1, 1895	$27,355.00		
Interest on fund January 1, 1896	27,360.00		
		54,715.00	
Interest to January 1, 1896, on West Shore bonds		1,680.00	
			$119,396.74
Cash from sales of publications		162.15	
Cash from repayments, freight, etc		6,312.46	
			6,474.61
Total receipts			125,871.35

EXPENDITURES.

Building:			
Repairs, care, and improvements	6,625.65		
Furniture and fixtures	422.67		
		7,048.32	
General expenses:			
Postage and telegraph	362.41		
Stationery	728.19		
General printing	308.30		
Incidentals (fuel, gas, etc.)	7,095.54		
Library (books, periodicals)	1,750.93		
Salaries [1]	19,326.89		
Gallery of art	125.25		
		29,697.51	
Publications and researches:			
Smithsonian contributions	2,952.51		
Miscellaneous collections	2,036.63		
Reports	614.08		
Special publications	1,954.55		
Researches	6,138.62		
Apparatus	127.92		
Museum	298.72		
Hodgkins fund	13,668.57		
Explorations	700.00		
		28,491.60	
Literary and scientific exchanges		3,568.14	
			68,805.57
Balance unexpended June 30, 1896			57,065.78

The cash received from the sale of publications, from repayments for freights, etc., is to be credited to the items of expenditure as follows:

Smithsonian contributions	$50.30	
Miscellaneous collections	111.75	
Reports	.10	
		$162.15
Hodgkins fund		25.82
Museum		298.72

[1] In addition to the above $19,326.89 paid for salaries under general expenses, $11,973.12 were paid for services, viz, $2,115.75 charged to building account, $83.68 to furniture account, $956.12 to Hodgkins fund account, $700.08 to library account, $5,617.19 to researches account, $1,825 to special publications account, and $675 to miscellaneous collections account.

Exchanges	$3,469.72
Incidentals	2,018.20
Explorations	500.00
Total	6,474.61

The net expenditures of the Institution for the year ending June 30, 1896, including $11,000 paid for prizes awarded from the Hodgkins fund in accordance with the recommendation of the award committee, were, therefore, $62,330.96, or $6,474.61 less than the gross expenditures, $68,805.57, as above stated.

All moneys received by the Smithsonian Institution from interest, sales, refunding of moneys temporarily advanced, or otherwise, are deposited with the Treasurer of the United States to the credit of the Secretary of the Institution, and all payments are made by his checks on the Treasurer of the United States.

Your committee also presents the following statements in regard to appropriations and expenditures for objects intrusted by Congress to the care of the Smithsonian Institution:

Detailed statement of disbursements from appropriations committed by Congress to the care of the Smithsonian Institution for the fiscal year ending June 30, 1896, and from balances of former years.

INTERNATIONAL EXCHANGES.

Receipts.

Appropriated by Congress for the fiscal year ending June 30, 1896, "for expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees" (sundry civil act, March 2, 1895)	$17,000.00

Disbursements from July 1, 1895, to June 30, 1896.

Salaries or compensation:	
1 curator, 12 months, at $225	$2,700.00
1 clerk, $4\frac{1}{2}$ months 5 days, at $160	746.67
1 chief clerk, 2 months, at $150	300.00
1 clerk {6 months, at $120	720.00
6 months, at $130	780.00
1 clerk, 2 months, at $100	200.00
1 clerk {6 months, at $85	510.00
$5\frac{1}{2}$ months 9 days, at $91.66	531.63
6 days, at $100	20.00
1 clerk {6 months, at $80	480.00
6 months, at $85	510.00
1 clerk, 12 months, at $75	900.00
1 {clerk, 5 months, at $75	375.00
laborer, 182 days, at $1.50	273.00
1 clerk {6 months, at $65	390.00
6 months, at $70	420.00
1 clerk, 6 months, at $60	360.00
1 {copyist, 6 months, at $50	300.00
$5\frac{1}{2}$ months 9 days, at $55	319.00
stenographer, 6 days, at $60	12.00

Salaries or compensation—Continued.

1 packer	6 months, at $50	$300.00	
	2½ months 8 days, at $55	151.70	
1 clerk, 11½ months, at $45		517.50	
1 clerk, 2 months 20 days, at $35		92.58	
1 copyist, 4½ months, at $35		157.50	
1 messenger, 6 months 16 days, at $25		162.90	
1 carpenter	22 days, at $3	66.00	
	12¼ days, at $3	36.75	
	20 days, at $3	60.00	
1 painter, 5 days, at $2		10.00	
1 laborer	79 days, at $1.50	118.50	
	224 days, at $1.50	336.00	
1 cleaner, 13 days, at $1		13.00	
1 agent, 12 months, at $50		600.00	
1 agent	6 months, at $83.33⅓	500.00	
	6 months, at $91.66⅔	550.00	
Total salaries of compensation		14,519.73	

General expenses:

Freight	$1,502.32		
Printing	9.50		
Postage and telegrams	20.32		
Supplies	193.03		
Traveling expenses	574.18		
		2,299.35	
Total disbursements			$16,819.08
Balance July 1, 1896			180.92

INTERNATIONAL EXCHANGES, SMITHSONIAN INSTITUTION, 1895.

Balance July 1, 1895, as per last report	$2.01

Disbursements.

Supplies	1.80
Balance July 1, 1896	.21

INTERNATIONAL EXCHANGES, 1894.

Balance July 1, 1895, as per last report $0.10

Balance carried, under the provisions of the Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1896.

NORTH AMERICAN ETHNOLOGY, 1896.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for continuing ethnological researches among the American Indians, under the direction of the Smithsonian Institution, including salaries or compensation of necessary employees, $40,000, of which sum not exceeding $1,000 may be used for rent of building" (sundry civil act, March 2, 1895) $40,000.00

The actual conduct of these investigations has been continued by the Secretary in the hands of Maj. J. W. Powell, Director of the Bureau of American Ethnology.

Disbursements July 1, 1895, to June 30, 1896.

Salaries or compensation:		
1 Director, 12 months, at $375		$4,500.00
1 ethnologist in charge, 12 months, at $300		3,600.00
1 special ethnologist, 7 months, at $200		1,400.00
1 ethnologist, 12 months, at $150		1,800.00
1 ethnologist, 12 months, at $150		1,800.00
1 ethnologist, 12 months, at $150		1,800.00
1 ethnologist, 12 months, at $125		1,500.00
1 ethnologist, 12 months, at $125		1,500.00
1 ethnologist, 12 months, at $116.66		1,399.92
1 ethnologist, 12 months, at $110		1,320.00
1 ethno-photographer { 2 months, at $100		200.00
10 months, at $116.66		1,166.60
1 clerk, 12 months, at $100		1,200.00
1 clerk, 3 months, at $100		300.00
1 clerk { 6 months, at $83.33		499.98
6 months, at $100		600.00
1 clerk { 5 months, at $75		375.00
29 days, at $75		70.17
6 months, at $83.33		499.98
1 clerk, 12 months, at $75		900.00
1 clerk, 12 months, at $75		900.00
1 messenger, 12 months, at $60		720.00
1 messenger, 12 months, at $50		600.00
1 modeler, 10 months, at $60		600.00
1 skilled laborer { 6 months, at $40		240.00
6 months, at $45		270.00
1 copyist, 6 days, at $2		12.00
Total salaries or compensation		29,773.65
Miscellaneous:		
Drawings and illustrations	$290.50	
Freight	31.40	
Miscellaneous	92.10	
Postage and telegraph	35.91	
Publications	218.48	
Office furniture	393.77	
Office rental	999.96	
Special services	440.00	
Specimens	21.48	
Stationery	474.59	
Supplies	617.81	
Traveling and field expenses	5,166.22	
Total miscellaneous		8,782.22
Total disbursements		38,555.87
Balance July 1, 1896		1,444.13

NORTH AMERICAN ETHNOLOGY, 1895.

Balance July 1, 1895, as per last report	$5,680.15

Disbursements:

Drawings and illustrations	$708.50	
Freight	15.15	
Miscellaneous	12.97	
Office furniture	216.50	
Office rental	83.33	
Postage, telegraph, etc	20.30	
Publications	655.26	
Services	343.33	
Specimens	12.91	
Stationery	147.03	
Supplies	301.93	
Traveling and field expenses	1,266.50	
Total disbursements	3,783.71	
Amount carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1896, by decision of the Comptroller of the Treasury	1,796.36	
		$5,580.07
Balance July 1, 1896		100.08

NATIONAL MUSEUM.

PRESERVATION OF COLLECTIONS, JULY 1, 1895, TO JUNE 30, 1896.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government, and from other sources, including salaries or compensation of all necessary employees" (sundry civil act, March 2, 1895)	$143,225.00

Expenditures.

Salaries or compensation:

DIRECTION.

1 assistant secretary of the Smithsonian Institution, in charge, 12 months, at $333.33	$3,999.96

SCIENTIFIC STAFF.

1 executive curator, 7 months, at $225	1,575.00
3 curators, 12 months, at $200	7,200.00
1 curator, 12 months, at $175	2,100.00
1 curator, 11 months, at $175	1,925.00
1 curator, 1 month, at $166.73; 11 months, at $166.66	1,999.99
1 curator (acting), 1 month, at $142; 2 months, at $140; 7 days, at $140.	453.61
1 assistant curator, 12 months, at $150	1,800.00
1 assistant curator, 11 months, at $133.33; 1 month, at $133.66	1,600.29
1 assistant curator, 12 months, at $125	1,500.00
1 assistant curator, 11 months, at $125; 1 month, at $126	1,501.00
1 assistant curator, 11 months, at $100; 1 month, at $103	1,203.00
1 assistant curator, 12 months, at $80	960.00
1 assistant curator, 11 months, at $75; 1 month, at $76.80	901.80
2 aids, 12 months, at $100	2,400.00
1 aid, 11 months, at $80; 1 month, at $80.80	960.80
1 aid, 4 months, at $70	280.00
1 aid, 34 days, at $60	65.80

Salaries or compensation—Continued.

1 aid, 2 months, at $50; 15 days, at $50	$125.00
1 aid, 7 months, at $40; 15 days, at $40	300.69
1 aid, 4 months, at $40	160.00
1 collector, 3 months, at $60	180.00

PREPARATORS.

1 photographer, 12 months, at $158.33	1,899.96
1 artist, 12 months, at $110	1,320.00
1 osteologist, 8 months, at $90	720.00
1 preparator, 12 months, at $80	960.00
1 preparator, 2 months, at $90	180.00
1 preparator, 11 months, at $80; 15 days, at $80	918.71
1 preparator, 11 months, at $80; 15 days, at $80	918.71
1 preparator, 12 months, at $60	720.00
1 preparator, 1 month, at $60; 11 days, at $60	81.29
1 preparator, 10 months, at $50; 16 days, at $50	525.81
1 preparator, 4 months, at $50	200.00
1 preparator, 1 month, at $50; 23 days, at $50	87.10
1 preparator, 23 days, at $3.20	73.60
1 preparator, 24 days, at $3.20	76.80
1 taxidermist, 10 months, at $100; 32½ days, at $100	1,106.99
1 taxidermist, 7 months, at $100; 38 days, at $100	824.52
1 taxidermist, 12 months, at $90	1,080.00
1 taxidermist, 2 months, at $75; 14 days, at $75	185.00
1 taxidermist, 10 months, at $60; 29 days, at $60; 29 days, at $60	714.13
1 model maker, 5 months, at $100; 9 days, at $100	529.03

CLERICAL STAFF.

1 chief clerk, 12 months, at $200	2,400.00
1 editor, 8 months, at $187.50; 19 days, at $187.50	1,614.92
1 editor, 2 months, at $166.66; 1 month, at $166.73	500.05
1 chief of division, 12 months, at $200	2,400.00
1 registrar, 11 months, at $158.33; 1 month, at $160.06	1,901.69
1 disbursing clerk, 12 months, at $116.66	1,399.92
1 assistant librarian, 11 months, at $110; 1 month, at $111.40	1,321.40
1 stenographer, 10 months, at $110; 2 months, at $120	1,340.00
1 stenographer, 11 months, at $50; 1 month, at $54	604.00
1 stenographer, 12 months, at $45	540.00
1 typewriter, 10 months, at $50; 50 days, at $50	582.10
1 typewriter, 309 days, at $1.50; 6 days, at $50 per month	473.50
2 clerks, 12 months, at $115	2,760.00
2 clerks, 12 months, at $100	2,400.00
1 clerk, 6 months, at $100	600.00
1 clerk, 8 months, at $90; 9 days, at $90	746.13
1 clerk, 12 months, at $90	1,080.00
1 clerk, 10 months, at $60; 2 months, at $90	780.00
1 clerk, 12 months, at $83.33	999.96
1 clerk, 11 months, at $75	825.00
1 clerk, 1 month, at $70	70.00
2 clerks, 12 months, at $60	1,440.00
1 clerk, 4 months, at $60; 3 months, at $50; 15 days, at $50	415.00
2 clerks, 12 months, at $55	1,320.00
1 clerk, 11 months, at $55; 1 month, at $54	659.00
1 clerk, 11 months, at $55; 1 month, at $54	659.00

Salaries or compensation—Continued.

1 clerk, 11 months, at $50; 1 month, at $51	$601.00
1 clerk, 11 months, at $50; 3 days, at $50	554.84
5 clerks, 12 months, at $50	3,000.00
1 clerk, 6 months, at $50	300.00
1 copyist, 12 months, at $45	540.00
2 copyists, 2 months, at $45; 15 days, at $45	225.00
2 copyists, 11 months, at $40; 1 month, at $41	962.00
4 copyists, 12 months, at $40	1,920.00
1 copyist, 11 months, at $35; 1 month, at $36	421.00
2 copyists, 12 months, at $35	840.00
1 copyist, 10 months, at $35; 13 days, at $35	364.68
1 copyist, 5 months, at $35; 22 days, at $35	199.84
1 copyist, 3 months, at $35	105.00
2 copyists, 12 months, at $30	720.00
1 copyist, 12 months, at $25	300.00
1 copyist, 4½ months, at $25; 22 days, at $25	130.24
1 copyist, 4 months, at $20; 31 days, at $20	100.22

BUILDINGS AND LABOR.

1 superintendent, 12 months, at $137.50	1,650.00
1 assistant superintendent, 3 months, at $100; 9 months, at $110	1,290.00
1 foreman, 12 months, at $50	600.00
1 chief of watch, 12 months, at $65	780.00
1 chief of watch, 11 months, at $65; 28 days, at $65	775.67
1 chief of watch, 11 months, at $50; 1 month, at $53	603.00
1 watchman, 12 months, at $65	780.00
10 watchmen, 12 months, at $50	6,000.00
1 watchman, 6 months, at $50; 64 days, at $50	406.40
1 watchman, 6 months, at $50	300.00
1 watchman, 3 months, at $45; 26 days, at $45	172.74
1 watchman, 5 months, at $45; 18 days, at $45	251.13
2 watchmen, 12 months, at $45	1,080.00
1 watchman, 11 months, at $45; 1 month, at $48	543.00
1 watchman, 11 months, at $40; 23 days, at $40	470.67
1 watchman, 12 months, at $40	480.00
1 watchman, 11 months, at $45; 13 days, at $45	513.87
1 watchman, 4 months, at $45; 23 days, at $45	215.69
1 watchman, 9 months, at $45; 30 days, at $45	464.47
1 watchman, 4 months, at $45	180.00
1 watchman (acting), 3 months, at $35; 36 days, at $35	147.40
1 watchman, 123 days, at $1.50	184.50
1 watchman, 3 days, at $1.50	4.50
1 skilled laborer, 2 months, at $62; 9 months, at $50; 1 month, at $40	614.00
1 skilled laborer, 3 months, at $60; 31 days, at $60	240.00
1 skilled laborer, 21 days, at $50	33.87
1 skilled laborer, 11 months, at $45	495.00
1 skilled laborer, 231 days, at $2	462.00
1 skilled laborer, 13 days, at $1.75	22.75
1 laborer, 1 month, at $53.50; 1 month, at $47.50; 1 month, at $46; 6 months, at $40	387.00
1 laborer, 1 month, at $49.50; 317 days, at $1.50	525.00
1 laborer, 12 months, at $45	540.00
1 laborer, 11 months, at $45	495.00
1 laborer, 1 month, at $43; 2 months, at $41.50; 8 months, at $40	446.00

Salaries or compensation—Continued.

1 laborer, 1 month, at $43; 10 months, at $40; 15 days, at $40	$463.00
1 laborer, 1 month, at $41.50; 11 months, at $40	481.50
1 laborer, 1 month, at $41.50; 11 months, at $40	481.50
2 laborers, 12 months, at $40	960.00
1 laborer, 11 months, at $40; 15 days, at $40	460.00
1 laborer, 11 months, at $40; 28 days, at $40	476.13
1 laborer, 11 months, at $40; 24 days, at $40	472.00
7 laborers, 314 days, at $1.50	3,297.00
1 laborer, 255 days, at $1.50	382.50
1 laborer, 92 days, at $1.50	138.00
1 laborer, 316 days, at $1.50	474.00
1 laborer, 28½ days, at $1.50; 281 hours, at 15 cents per hour	84.90
1 laborer, 305 days, at $1.50	457.50
1 laborer, 13 days, at $1.50	19.50
1 laborer, 271 days, at $1.50	406.50
1 laborer, 363 days, at $1.50	544.50
1 laborer, 362 days, at $1.50	543.00
1 laborer, 349 days, at $1.50	523.50
1 laborer, 329 days, at $1.50	493.50
1 laborer, 293 days, at $1.50	439.50
1 laborer, 6 days, at $1.50	9.00
1 laborer, 89½ hours, at 15 cents	13.43
1 laborer, 82½ hours, at 15 cents	12.34
1 laborer, 90 hours, at 15 cents	13.50
1 laborer, 81¾ hours, at 15 cents	12.26
1 laborer, 88½ hours, at 15 cents	13.28
1 laborer, 143¼ hours, at 15 cents	21.49
1 laborer, 90¼ hours, at 15 cents	13.54
1 laborer, 285 hours, at 15 cents	42.83
1 laborer, 109 hours, at 15 cents	16.35
1 laborer, 86¾ hours, at 15 cents	13.01
1 laborer, 13 hours, at 15 cents	1.95
1 laborer, 78½ hours, at 15 cents	11.78
1 laborer, 10 hours, at 15 cents	1.50
1 laborer, 11 days, at $1.50	16.50
1 messenger, 10 months, at $50; 30 days, at $50	550.00
1 messenger, 11 months, at $30; 29 days, at $30	359.00
1 messenger, 2 months, at $30	60.00
1 messenger, 16 days, at $30	16.00
1 messenger, 11 months, at $25	275.00
1 messenger, 1 month, at $22; 5 months, at $20; 6 months, at $15	212.00
2 messengers, 12 months, at $20	480.00
1 messenger, 1 month, at $20; 21 days, at $20	33.55
1 messenger, 31 days, at $20	20.41
1 attendant, 12 months, at $40	480.00
3 cleaners, 12 months, at $30	1,080.00
1 cleaner, 315 days, at $1	315.00
1 cleaner, 315 days, at $1	315.00
1 cleaner, 11 months, at $30; 1 month, at $31	361.00
Total salaries	125,950.49
Special services	2,916.25
Total services	128,866.74

Miscellaneous:		
Supplies	$2,504.70	
Stationery	765.96	
Specimens	3,810.25	
Books and periodicals	2,245.39	
Travel	599.35	
Freight and cartage	1,586.08	
		$11,511.73
Total expenditure		140,378.47
Balance July 1, 1896, to meet liabilities		2,846.53

NATIONAL MUSEUM: FURNITURE AND FIXTURES, JULY 1, 1895, TO JUNE 30, 1896.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for cases, furniture, fixtures, and appliances required for the exhibition and safe-keeping of the collections of the National Museum, including salaries or compensation of all necessary employees" (sundry civil act, March 2, 1895)	$12,500.00

Expenditures.

Salaries or compensation:		
1 cabinetmaker, 314 days, at $3		942.00
1 carpenter, 314 days, at $3		942.00
1 carpenter, 156 days, at $3		468.00
1 carpenter, 123 days, at $3		369.00
1 carpenter, 109 days, at $3		327.00
1 carpenter, 103 days, at $3		309.00
1 carpenter, 95 days, at $3		285.00
1 carpenter, 72 days, at $3		216.00
1 carpenter, 58 days, at $3		174.00
1 carpenter, 17 days, at $3		51.00
1 carpenter, 12½ days, at $3		37.50
1 carpenter, 12 days, at $3		36.00
1 carpenter, 10 days, at $3		30.00
1 carpenter, 9 days, at $3		27.00
1 carpenter, 8 days, at $3		24.00
1 carpenter, 2 days, at $3		6.00
1 painter, 3 months, at $65; 21 days, at $65		245.95
1 painter, 10 months, at $50		500.00
1 skilled laborer, 218 days, at $2		436.00
1 skilled laborer, 26 days, at $2		52.00
1 skilled laborer, 19½ days, at $2		39.00
1 skilled laborer, 1 month, at $60		60.00
1 skilled laborer, 139 days, at $1.75		243.25
1 laborer, 26 days, at $1.50		39.00
1 copyist, 6 days, at $40		8.00
Total salaries		5,866.70
Special services		394.75
Total services		6,261.45
Miscellaneous:		
Cases	$300.00	
Drawings	22.88	
Drawers	1,055.75	
Frames	5.00	

Miscellaneous—Continued.		
Glass	$223.57	
Hardware	653.05	
Tools	18.96	
Cloth	111.73	
Glass jars	414.61	
Lumber	947.54	
Paints, oils	346.30	
Office furniture	193.36	
Rubber and leather	70.26	
Apparatus	6.45	
Plumbing	463.00	
Iron brackets	91.00	
		$4,923.46
Total expenditures		11,184.91
Balance July 1, 1896, to meet liabilities		1,315.09

NATIONAL MUSEUM: HEATING, LIGHTING, ELECTRIC AND TELEPHONIC SERVICE, JULY 1, 1895, TO JUNE 30, 1896.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for expense of heating, lighting, electrical, telegraphic, and telephonic service for the National Museum" (sundry civil act, March 2, 1895)	$13,000.00

Expenditures.

Salaries or compensation:		
1 engineer, 12 months, at $115		1,380.00
1 assistant engineer, 3 months, at $75; 53 days, at $75		354.27
3 firemen, 12 months, at $50		1,800,00
1 fireman, 6 days, at $50		9.68
1 fireman, 5½ days, at $50		9.48
1 fireman, 1¾ days, at $50		2.81
1 skilled laborer, 12 months, at $75		900.00
1 skilled laborer, 6 months, at $60		360.00
1 telephone clerk, 20 days, at $60		38.71
1 telephone clerk, 6 days, at $45		9.00
1 laborer, 2 months, at $40; 24 days, at $40; 6 days, at $45		121.00
		4,984.95
Special services		39.50
Total services		5,024.45
General expenses:		
Coal and wood	$3,202.32	
Gas	1,540.63	
Telephones	412.50	
Electric supplies	1,482.44	
Rental of call boxes	110.00	
Heating supplies	167.72	
Telegrams	8.61	
Heating repairs	104.00	
		7,028.22
Total expenditure		12,052.67
Balance July 1, 1896, to meet liabilities		947.33

National Museum: Postage, July 1, 1895, to June 30, 1896.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for postage stamps and foreign postal cards for the National Museum" (sundry civil act, March 2, 1895) $500.00

Disbursements.

Washington city post-office, for stamps, etc 500.00

National Museum: Printing, July 1, 1895, to June 30, 1896.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for the Smithsonian Institution for printing labels and blanks, and for the 'Bulletins' and annual volumes of the 'Proceedings' of the National Museum, and binding scientific books and pamphlets presented to and acquired by the National Museum Library" (sundry civil act, March 2, 1895) $12,000.00

Expenditures.

Bulletins, National Museum, Nos. 47, 49, and special bulletins Nos. 2 and 3	$7,036.64	
Proceedings National Museum, Vol. XVIII	956.50	
Reports National Museum, extras	201.62	
Labels	2,685.91	
Letter heads, pads, and envelopes	205.09	
Blanks	423.48	
Electros	9.25	
Binding	388.60	
Congressional Records	40.20	
Total expenditure		11,947.29
Balance July 1, 1896		52.71

National Museum: Rent of Workshops, 1896.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for rent of workshops for the National Museum" (sundry civil act, March 2, 1895) $900.00

Disbursements.

Rent, July 1 to May 31, 11 months, at $75	825.00
Balance July 1, 1896	75.00

National Museum: Building Repairs, 1896.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for repairs to buildings, shops, and sheds, National Museum, including all necessary labor and material" (sundry civil act, March 2, 1895) $4,000.00

Expenditures.

Services or compensation:			
3 carpenters, 208 days, at $3		$624.00	
1 painter, 1 month, at $65		65.00	
1 painter, 16 days at $65		33.55	
14 skilled laborers, 364 days at $2		728.00	
1 skilled laborer, 21 days at $1.75		36.75	
3 skilled laborers, 1 month at $50		150.00	
1 skilled laborer, 7½ days at $50		12.10	
1 skilled laborer, 1 month at $52		52.00	
1 skilled laborer, 24 days at $50, 6 days at $55		51.00	
1 skilled laborer, 21 days at $1.75, 5 days at $2		46.75	
1 laborer, 1 month, $41.50		41.50	
3 laborers, 83 days at $1.50		124.50	
		1,965.15	
Miscellaneous:			
Granito pavement	$600.00		
Paints, oils, etc	400.23		
Glass	28.00		
Advertising	38.19		
Lumber	9.00		
Hardware	6.42		
Brick, cement, charcoal	23.50		
		1,105.34	
Total expenditure			$3,070.49
Balance July 1, 1896, to meet liabilities			929.51

FIRE PROTECTION: SMITHSONIAN INSTITUTION AND NATIONAL MUSEUM, 1896.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1896, "for expenses of putting in four additional fire-plugs in the Smithsonian grounds for the better protection of the Smithsonian Institution, National Museum, and Astrophysical Observatory, and the purchase of necessary fire hose." (Sundry civil act, March 2, 1895.)	$800.00

Disbursements.

Water Department, District of Columbia, for labor and material for erecting four fire-hydrants in Smithsonian grounds	$646.89	
Fire hose, nozzles, and couplings	151.40	
		798.29
Balance July 1, 1896		1.71

APPROPRIATIONS FOR PREVIOUS YEARS—PRESERVATION OF COLLECTIONS, 1894.

Balance July 1, 1895, as per last annual report		$235.27

Expenditures.

Specimens	$13.50	
Freight	12.14	
Books	202.23	
Total expenditure		227.87
Balance July 1, 1896		7.40

TOTAL EXPENDITURE OF THE APPROPRIATION FOR PRESERVATION OF COLLECTIONS, 1894.

Appropriation		$132,500.00
Expenditures.		
Salaries or compensation	$118,406.94	
Special or contract work	2,242.32	
Total salaries	120,649.26	
Supplies	2,356.36	
Stationery	496.05	
Specimens	3,824.24	
Travel	572.30	
Freight	3,129.48	
Books	1,464.91	
Total expenditure		132,492.60
Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1896		7.40

PRESERVATION OF COLLECTIONS, 1895.

Balance July 1, 1895, as per last annual report		$4,950.88
Expenditures, July 1, 1895, to June 30, 1896.		
Special or contract services	$683.09	
Supplies	907.09	
Stationery	264.38	
Specimens	999.33	
Books and periodicals	1,518.14	
Travel	90.61	
Freight and cartage	445.93	
Total expenditure, July 1, 1895, to June 30, 1896		4,908.57
Balance July 1, 1896		42.31

TOTAL EXPENDITURE OF THE APPROPRIATION FOR PRESERVATION OF COLLECTIONS, 1895.

Appropriation		$143,000.00
Expenditures.		
Salaries or compensation	$126,142.26	
Special or contract work	4,064.33	
Total services	130,206.59	
Supplies	3,183.65	
Stationery	1,076.00	
Specimens	3,366.47	
Travel	676.25	
Freight	1,915.91	
Books	2,532.82	
Total expenditure		142,957.69
Balance July 1, 1896		42.31

Furniture and Fixtures, 1894.

Balance July 1, 1895, as per last annual report	$0.09

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1896.

Furniture and Fixtures, 1895.

Balance July 1, 1895, as per last annual report		$697.43
Expenditures.		
Special services	$7.00	
Miscellaneous:		
Drawers, trays, boxes	7.00	
Frames, stands, etc	1.25	
Glass	1.25	
Hardware	37.69	
Tools	1.10	
Cloth, cotton, etc	97.78	
Glass jars	106.57	
Lumber	143.36	
Paints, oils, etc	38.24	
Office furniture	241.03	
Metals	6.24	
Rubber and leather	5.79	
Apparatus and chemicals	2.60	
Total expenditure		696.90
Balance July 1, 1896		.53

Total Expenditure of the Appropriation for Furniture and Fixtures, 1895.

Appropriation		$10,000.00
Salaries or compensation	$5,609.20	
Special contract work	93.13	
Total services	5,702.33	
Drawings	91.25	
Drawers, trays, boxes	678.79	
Frames, stands, etc	68.25	
Glass	47.15	
Hardware	547.99	
Tools	64.79	
Cloth, cotton, etc	117.78	
Glass jars	354.89	
Lumber	1,251.58	
Paints, oils	488.38	
Office furniture	363.76	
Metals	53.40	
Rubber and leather	21.59	
Iron brackets	141.94	
Apparatus and chemicals	2.60	
Total expenditure		9,999.47
Balance July 1, 1896		.53

HEATING, LIGHTING, ETC., 1894.

Balance July 1, 1895, as per last annual report		$0.76

Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1896.

HEATING, LIGHTING, ELECTRIC, AND TELEPHONIC SERVICE, 1895.

Balance July 1, 1895, as per last annual report		$1,445.07
Expenditures.		
Special services	$6.25	
General expenses:		
Coal and wood	7.76	
Gas	101.25	
Telephones	158.45	
Electric supplies	1,114.82	
Rental of call boxes	30.00	
Heating supplies	18.99	
Telegrams	6.40	
Total expenditures		1,443.92
Balance July 1, 1896		1.15

TOTAL EXPENDITURE OF THE APPROPRIATION FOR HEATING, LIGHTING, ETC., 1895.

Appropriation		$13,000.00
Expenditures.		
Salaries	$6,177.43	
Special services	57.50	
Total services	6,234.93	
General expenses:		
Coal and wood	2,799.66	
Gas	1,557.13	
Telephones	602.45	
Electric supplies	1,325.57	
Rental of call boxes	120.00	
Heating supplies	346.40	
Telegrams	12.71	
Total expenditure		12,998.85
Balance July 1, 1896		1.15

NATIONAL MUSEUM: BUILDING REPAIRS, 1895.

Balance July 1, 1895, as per last report	$13.29
Disbursements.	
Advertising proposals	8.51
Balance July 1, 1896	4.78

NATIONAL MUSEUM: RENT OF WORKSHOPS, 1895.

Balance July 1, 1895, as per last report	$52.54
Disbursements.	
Rent	40.00
Balance July 1, 1896	12.54

ASTROPHYSICAL OBSERVATORY—SMITHSONIAN INSTITUTION, 1896.

Receipts.

Appropriation by Congress "for maintenance of Astrophysical Observatory under the direction of the Smithsonian Institution, including salaries of assistants, apparatus, and miscellaneous expenses (sundry civil act, March 2, 1895) $9,000.00

Disbursements from July 1, 1895, to June 30, 1896.

Salaries or compensation:			
1 aid, 6 months, at $125		$750.00	
1 aid, 4 months 7 days, at $100		422.58	
1 assistant, 10½ months, at $100		1,050.00	
1 assistant, 27 days, at $100		88.06	
1 assistant, 6 days, at $133.34		26.67	
1 junior assistant, 11 months 9 days, at $83.33		983.29	
1 junior assistant, 6 days, at $100		20.00	
1 clerk, 1 month, at $100		100.00	
1 clerk, 5 months 6 days, at $60		311.61	
1 instrument maker, 6 months, at $65		390.00	
1 instrument maker, 121¼ days, at $65		290.08	
1 instrument maker, 51¼ days, at $3.50		179.38	
1 clerk, 2 months, at $35		70.00	
1 clerk, 2 months, at $40		80.00	
1 computer, 2 months six days, at $50		110.00	
1 machinist, one-half month, at $83.33		41.67	
1 machinist, 1⅝ days, at $3		4.88	
1 steam fitter, three-fourths day, at $3		2.25	
1 steam fitter, 5 days, at $3		15.00	
1 carpenter, 30 days, at $3		90.00	
1 carpenter, 20¾ days, at $3		62.25	
1 carpenter, 27½ days, at $3		82.50	
1 carpenter, 18½ days, at $3		55.50	
1 skilled laborer, 7⅛ days, at $2.50		17.82	
1 laborer, three-fourths day, at $2		1.50	
1 laborer, 244½ days, at $1.50		366.75	
1 laborer, 4 days, at $1.50		6.00	
1 cleaner, 2½ days, at $1		2.50	
Total salaries or compensation		5,620.29	
General expenses:			
Apparatus	$1,233.60		
Books and binding	54.89		
Building	9.00		
Castings	26.33		
Freight	47.53		
Heating apparatus	330.81		
Illustrations	20.00		
Lumber	90.52		
Office furniture	9.00		
Postage and telegraph	5.18		
Stationery	19.02		
Supplies	718.63		
Traveling expenses	116.95		
		2,681.46	
Total disbursements			8,301.75
Balance July 1, 1896			698.25

ASTROPHYSICAL OBSERVATORY, 1895.

Balance July 1, 1895, as per last report		$1,585.01

Disbursements, July 1, 1895, to June 30, 1896.

General expenses:		
Apparatus	$931.41	
Books	47.56	
Building	9.80	
Freight	16.23	
Heating apparatus	270.00	
Lumber	1.08	
Postage and telegraph	2.48	
Supplies	284.43	
Traveling expenses	17.60	
		1,580.59
Balance July 1, 1896		4.42

ASTROPHYSICAL OBSERVATORY, 1894.

Balance July 1, 1895, as per last report	$9.02

Disbursements.

Apparatus	2.75
Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1896.	6.27

NATIONAL ZOOLOGICAL PARK, 1896.

Appropriation by Congress "for continuing the construction of roads, walks, bridges, water supply, sewerage, and drainage, and for grading, planting, and otherwise improving the grounds, erecting and repairing buildings and inclosures for animals, and for administrative purposes, care, subsistence, and transportation of animals, including salaries or compensation of all necessary employees, and general incidental expenses, not otherwise provided for, fifty-five thousand dollars, one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States, and of the sum hereby appropriated five thousand dollars shall be used toward the construction of a road from the Holt mansion entrance (on Adams' Mill road) into the park to connect with the roads now in existence, including a bridge across Rock Creek" (sundry civil act, March 2, 1895)	$55,000.00

Disbursements, July 1, 1895, to June 30, 1896.

Salaries or compensation:	
1 superintendent, 12 months, at $208.33	$2,499.96
1 property clerk, 12 months, at $125	1,500.00
1 clerk, 12 months, at $60	720.00
1 messenger {6 months, at $40	240.00
6 months, at $50	300.00
1 foreman, 12 months, at $75	900.00
1 assistant foreman, 11 months, at $60	660.00
1 head keeper {11½ months, at $83.33	958.29
9 days, at $83.33	25.00
6days, at $100	20.00

Salaries or compensation—Continued.

1 under keeper	11½ months, at $50	$575.00	
	9 days, at $50	15.00	
	6 days, at $60	12.00	
1 under keeper	11½ months, at $50	575.00	
	9 days, at $50	15.00	
	6 days, at $60	12.00	
1 under keeper	11½ months, at $50	575.00	
	9 days, at $50	15.00	
	6 days, at $60	12.00	
1 under keeper	11 months, at $50	550.00	
	21 days, at $50	34.35	
	6 days, at $2	12.00	
1 under keeper	11½ months, at $50	575.00	
	9 days, at $50	15.00	
	6 days, at $60	12.00	
1 keeper, 10 months, at $75		750.00	
1 blacksmith, 12 months, at $75		900.00	
1 assistant blacksmith, 12 months, at $60		720.00	
1 carpenter, 12 months, at $75		900.00	
1 engineer	3½ months, at $50	175.00	
	1 day, at $50	1.61	
1 stenographer, 12 months, at $62.50		750.00	
1 copyist, 3½ days, at $50		5.83	
1 attendant	11½ months, at $15	172.50	
	9 days, at $15	4.50	
	6 days, at $20	4.00	
1 watchman, 12 months, at $50		600.00	
1 watchman, 12 months, at $50		600.00	
1 watchman, 12 months, at $60		720.00	
1 watchman, 3 months, at $50		150.00	
1 night watchman, 12 months, at $50		600.00	
1 laborer	11 months, at $45	495.00	
	9 days, at $45	13.50	
	6 days, at $50	10.00	
1 laborer	2 months, at $45	90.00	
	6 months, at $50	300.00	
1 laborer, 12 months, at $50		600.00	
1 laborer, 12 months, at $50		600.00	
1 laborer, 12 months, at $50		600.00	
1 laborer, 11½ months, at $50		575.00	
1 laborer, 12 months, at $35		420.00	
1 laborer	4 months, at $50	200.00	
	15 days, at $50	24.57	
1 laborer, 6 days, at $60		12.00	
Total salaries or compensation			$21,821.11
Miscellaneous:			
Buildings		158.46	
Building material		1,042.88	
Fencing and cage material		3,779.16	
Food		5,686.31	
Freight and transportation		651.68	
Fuel		614.73	
Lumber		878.27	

Miscellaneous—Continued.

Machinery, tools, etc	$442.49	
Miscellaneous supplies	1,386.57	
Paints, oils, glass	237.37	
Postage, telephones, and telegraph	182.12	
Road material and grading	721.22	
Surveying, plans, etc	1,127.50	
Stationery, books, printing, etc	236.41	
Trees, plants, etc	514.01	
Water supply, sewage, etc	357.84	
Total miscellaneous		$18,017.02

Wages of mechanics and laborers and hire of teams in constructing buildings and inclosures, laying water pipes, building roads, gutters, and walks, planting trees, and otherwise improving the grounds:

1 laborer, 27 days, at $2	$54.00
1 laborer { $35\frac{1}{2}$ days, at $2	71.00
{ $53\frac{3}{4}$ days, at $1.50	80.63
1 laborer { $264\frac{3}{4}$ days, at $2	529.50
{ 26 days, at $1.50	39.00
1 laborer, 193 days, at $1.50	289.50
1 laborer, $64\frac{1}{2}$ days, at $1.50	96.75
1 laborer, $233\frac{1}{4}$ days, at $1.50	349.89
1 laborer, 120 days, at $1.50	180.00
1 laborer, $184\frac{1}{4}$ days, at $1.50	276.39
1 laborer, 78 days, at $1.50	117.00
1 laborer, $160\frac{1}{4}$ days, at $1.50	240.38
1 laborer, $113\frac{1}{2}$ days, at $1.50	170.25
1 laborer, $168\frac{3}{4}$ days, at $1.50	253.13
1 laborer, 339 days, at $1.50	508.50
1 laborer, 42 days, at $1.50	63.00
1 laborer, $360\frac{1}{4}$ days, at $1.50	540.38
1 laborer, $170\frac{1}{4}$ days, at $1.50	255.37
1 laborer, 355 days, at $1.50	532.50
1 laborer, $234\frac{1}{2}$ days, at $1.50	351.75
1 laborer, $46\frac{1}{2}$ days, at $1.50	69.75
1 laborer, $32\frac{1}{4}$ days, at $1.50	48.38
1 laborer, 138 days, at $1.50	207.00
1 laborer, 67 days, at $1.50	100.50
1 laborer, 11 days, at $1.50	16.50
1 laborer, $35\frac{3}{4}$ days, at $1.50	53.63
1 laborer, 17 days, at $1.50	25.50
1 laborer { $138\frac{1}{2}$ days, at $1.50	207.75
{ 125 days, at $1.25	156.25
1 laborer { 112 days, at $1.50	167.99
{ $50\frac{1}{2}$ days, at $1.25	63.12
1 laborer { $184\frac{1}{4}$ days, at $1.50	276.38
{ 21 days, at $1.25	26.25
1 laborer, $42\frac{1}{2}$ days, at $1.25	53.12
1 laborer, 366 days, at $1.25	457.50
1 laborer, $97\frac{1}{4}$ days, at $1.25	121.57
1 laborer, 18 days, at $1.25	22.50
1 laborer, $12\frac{3}{4}$ days, at $1.25	15.94
1 laborer, $12\frac{3}{4}$ days, at $1.25	15.94
1 laborer, $20\frac{3}{4}$ days, at $1.25	25.94

Wages of mechanics and laborers, etc.—Continued.

1 laborer, 31 days, at \$1.25	\$42.50
1 laborer, 20 days, at \$1.25	25.00
1 laborer, 25 days, at \$1.25	31.25
1 laborer, 22 days, at \$1.25	27.50
1 laborer, 34 days, at \$1.25	42.50
1 laborer, $229\frac{3}{4}$ days, at \$1.25	287.18
1 laborer, $80\frac{1}{4}$ days, at \$1.25	100.31
1 laborer, $74\frac{1}{2}$ days, at \$1.25	93.12
1 laborer, $180\frac{3}{4}$ days, at \$1.25	225.93
1 laborer, 35 days, at \$1.25	43.75
1 laborer, 10 days, at \$1.25	12.50
1 laborer, 13 days, at \$1.25	16.25
1 laborer, $41\frac{3}{4}$ days, at \$1.25	52.19
1 laborer, $19\frac{3}{4}$ days, at \$1.25	24.69
1 laborer, 8 days, at \$1.25	10.00
1 laborer, 12 days, at \$1.25	15.00
1 laborer, $71\frac{1}{4}$ days, at \$1.25	89.07
1 laborer: $44\frac{1}{2}$ days, at \$1.25	55.63
112 days, at \$1	112.00
1 laborer: 111 days, at \$1.25	138.75
12 days, at \$1	12.00
$124\frac{1}{4}$ days, at 75 cents	93.19
1 laborer, $13\frac{1}{2}$ days, at \$1	13.50
1 laborer, 5 days, at \$1	5.00
1 laborer, 20 days, at \$1	20.00
1 laborer, $12\frac{1}{2}$ days, at \$1.50	18.75
1 carpenter, 39 days, at \$2.50	97.50
1 laborer, 31 days, at \$1.50	46.50
1 carpenter, 7 days, at \$2.50	17.50
1 carpenter, 12 days, at \$2.50	30.00
1 carpenter, 35 days, at \$2.50	87.50
1 carpenter, 14 days, at \$2.50	35.00
1 engineer, 13 days, at \$2.50	32.50
1 engineer, 24 days, at \$2.50	60.00
1 engineer, 14 days, at \$2.50	35.00
1 painter, 6 days, at \$3	18.00
1 painter, 32 days, at \$3	96.00
1 painter, $5\frac{3}{4}$ days, at \$3	17.25
1 painter, 14 days, at \$3	42.00
1 stonecutter, $3\frac{1}{4}$ days, at \$4	13.00
1 wagon and team, $38\frac{1}{2}$ days, at \$3.50	134.75
1 wagon and team, $2\frac{1}{2}$ days, at \$3.50	8.75
1 wagon and team, 12 days, at \$3.50	42.00
1 wagon and team, $88\frac{1}{4}$ days, at \$3.50	308.88
1 horse and cart, $63\frac{1}{4}$ days, at \$1.75	110.69
1 horse and cart, one-half day, at \$1.75	.88
1 horse and cart, 8 days, at \$1.75	14.00
1 horse and cart, $8\frac{1}{2}$ days, at \$1.75	14.88
1 horse and cart, $7\frac{3}{4}$ days, at \$1.75	13.57
1 horse, 70 days, at 50 cents	35.00
1 horse, 41 days, at 50 cents	20.50
1 water boy, 62 days, at 75 cents	46.50
1 water boy, $34\frac{1}{4}$ days, at 50 cents	17.13
1 water boy, 50 days, at 50 cents	25.00
1 water boy, $50\frac{3}{4}$ days, at 50 cents	25.38

Wages of mechanics and laborers, etc.—Continued.

1 water boy, 30 days, at 50 cents	$15.00	
1 water boy, 1 day, at 50 cents	.50	
1 water boy, 1 day, at 50 cents	.50	
1 water boy, 13 days, at 50 cents	6.50	
1 water boy, 1 day, at 50 cents	.50	
1 stone breaker, 171$\frac{1}{12}$ cubic yards, at 60 cents	102.65	
1 stone breaker, 152$\frac{3}{4}$ cubic yards, at 60 cents	91.65	
1 stone breaker, 208 cubic yards, at 60 cents	124.80	
1 draftsman, 78$\frac{1}{2}$ days, at $2	157.00	
1 modeler, 28$\frac{1}{2}$ days, at $100	93.01	
1 modeler, 23 days, at $100	75.48	
1 modeler, 3 days, at $60	5.87	
Total		$10,856.61
Total disbursements		50,694.74
Balance July 1, 1896		4,305.26

ENTRANCE AND DRIVEWAY, ZOOLOGICAL PARK, DISTRICT OF COLUMBIA, 1895 AND 1896.

Balance July 1, 1895, as per last report			$2,224.67

Disbursements.

Salaries or compensation:

1 assistant engineer, four twenty-sevenths of a month, at $175		$25.93	
1 chainman, 9 days, at $2.25		20.25	
1 rodman, 11 days, at $780 per annum		23.32	
1 assistant foreman, 1 month, at $60		60.00	
1 wagon and team, 21$\frac{3}{4}$ days, at $3.50		76.12	
1 horse and cart, 5 days, at $1.75		8.75	
1 laborer, 25 days, at $1.50		37.50	
1 laborer, 13$\frac{3}{4}$ days, at $1.50		20.63	
1 laborer, 4 days, at $1.50		6.00	
1 laborer, 23 days, at $1.50		34.50	
1 laborer, 25$\frac{1}{4}$ days, at $1.50		37.88	
1 laborer, 24 days, at $1.50		36.00	
1 laborer, one-half month, at $50		25.00	
1 laborer, 22$\frac{1}{4}$ days, at $1.50		33.37	
1 laborer, one-half month, at $45		22.50	
1 laborer, 24$\frac{1}{2}$ days, at $1.50		36.75	
1 laborer, 21 days, at $1.25		26.25	
1 laborer, 13$\frac{1}{2}$ days, at $1.25		16.88	
1 laborer, 17$\frac{1}{4}$ days, at $1.25		21.56	
1 laborer, 27$\frac{1}{2}$ days, at $1.25		34.37	
1 laborer, 10 days, at $1.25		12.50	
1 water boy, 27 days, at 75 cents		20.25	
Total salaries or compensation		636.31	
General expenses:			
Freight	$1.70		
Grading, etc	1,161.17		
Lumber	31.58		
Miscellaneous supplies	10.92		
Surveying, maps, etc	287.50		
		1,492,87	
Total disbursements			$2,129.18
Balance July 1, 1896			95.49

NATIONAL ZOOLOGICAL PARK, 1895.

Balance July 1, 1895, as per last report		$1,083.96

Disbursements.

Building material	$3.63	
Food	449.36	
Fencing and cage material	10.68	
Freight and transportation	338.41	
Lumber	1.10	
Miscellaneous	26.38	
Paints, oils, glass, etc	2.40	
Postage, telegraph, and telephone	48.09	
Stationery, books, printing, etc	20.03	
Surveying plans, etc	130.00	
Traveling expenses	39.65	
Trees, plants, etc	10.55	
Water supply, sewerage, etc	1.20	
Total disbursements		1,081.48
Balance July 1, 1896		2.48

NATIONAL ZOOLOGICAL PARK, 1894.

Balance July 1, 1895, as per last report		$240.66

Disbursements.

Stationery, books, printing, etc	$0.71	
Surveying, plans, etc	239.95	
		240.66

RECAPITULATION.

The total amount of funds administered by the Institution during the year ending June 30, 1896, appears from the foregoing statements and the account books to have been as follows:

Smithsonian Institution.

From balance of last year, July 1, 1895		$63,001.74	
(Including cash from executors of Dr. J. H. Kidder)	$5,000.00		
(Including cash from gift of Alex. Graham Bell)	5,000.00		
	10,000.00		
From interest on Smithsonian fund for the year		54,715.00	
From sales of publications		162.15	
From repayments of freight, etc		6,312.46	
Interest on West Shore bonds		1,680.00	
			$125,871.35

Appropriations committed by Congress to the care of the Institution.

International Exchanges—Smithsonian Institution:		
From balance of 1893–94	$0.10	
From balance of 1894–95	2.01	
From appropriation for 1895–96	17,000.00	
		$17,002.11
North American Ethnology:		
From balance of last year, July 1, 1895	5,680.15	
From appropriation for 1895–96	40,000.00	
		45,680.15

Preservation of collections—Museum:		
From balance of 1893–94	$235.27	
From balance of 1894–95	4,950.88	
From appropriation for 1895–96	143,225.00	
		$148,411.15
Printing—Museum:		
From balance of 1894–95	37.82	
From appropriation for 1895–96	12,000.00	
		12,037.82
Furniture and fixtures—Museum:		
From balance of 1893–94	.09	
From balance of 1894–95	697.43	
From appropriation for 1895–96	12,500.00	
		13,197.52
Heating and lighting, etc.—Museum:		
From balance of 1893–94	.76	
From balance of 1894–95	1,445.07	
From appropriation for 1895–96	13,000.00	
		14,445.83
Rent of workshops, etc.—Museum:		
From balance of 1894–95	52.54	
From appropriation for 1895–96	900.00	
		952.54
Postage—Museum:		
From appropriation for 1895–96		500.00
Building repairs—Museum:		
From appropriation for 1894–95	13.29	
From appropriation for 1895–96	4,000.00	
		4,013.29
National Zoological Park:		
From balance of 1893–94	240.66	
From balance of 1894–95	1,083.96	
From appropriation for 1895–96	55,000.00	
		56,324.62
Entrance and driveway, Zoological Park, District of Columbia:		
Balance from appropriation, 1895–96		2,224.67
Fire protection—Smithsonian Institution and National Museum:		
From appropriation for 1895–96		800.00
Astro-Physical Observatory, Smithsonian Institution:		
From balance of 1893–94	$9.02	
From balance of 1894–95	1,585.01	
From appropriation for 1895–96	9,000.00	
		10,594.03

SUMMARY.

Smithsonian Institution	125,871.35	
Exchanges	17,002.11	
Ethnology	45,680.15	
Preservation of collections	148,411.15	
Printing	12,037.82	
Furniture and fixtures	13,197.52	
Heating and lighting	14,445.83	
Rent of workshop	952.54	
Postage	500.00	
National Museum, building repairs	4,013.29	
Fire protection, Smithsonian Institution and National Museum	800.00	
National Zoological Park	56,324.62	
Entrance and driveway, Zoological Park	2,224.67	
Astro-Physical Observatory	10,594.03	
		452,055.08

The committee has examined the vouchers for payment from the Smithsonian income during the year ending June 30, 1896, each of which bears the approval of the Secretary, or, in his absence, of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution.

The committee has also examined the accounts of the several appropriations committed by Congress to the Institution, and finds that the balances hereinbefore given correspond with the certificates of the disbursing clerk of the Smithsonian Institution, whose appointment as such disbursing officer has been accepted and his bond approved by the Secretary of the Treasury.

The quarterly accounts current, the vouchers, and journals have been examined and found correct.

Statement of regular income from the Smithsonian fund available for use in the year ending June 30, 1897.

Balance on hand June 30, 1896		$57,065.78
(Including cash from executors of J. H. Kidder)	$5,000.00	
(Including cash from Dr. Alex. Graham Bell)	5,000.00	
	10,000.00	
Interest due and receivable July 1, 1896	27,360.00	
Interest due and receivable January 1, 1897	27,360.00	
Interest, West Shore Railroad bonds, due July 1, 1896	840.00	
Interest, West Shore Railroad bonds, due January 1, 1897	840.00	
		56,400.00
Total available for the year ending June 30, 1897		113,465.78

Respectfully submitted.

J. B. HENDERSON,
WM. L. WILSON,
GARDINER G. HUBBARD,
Executive Committee.

WASHINGTON, D. C., *January 18, 1897.*

ACTS AND RESOLUTIONS OF CONGRESS RELATIVE TO THE SMITHSONIAN INSTITUTION, NATIONAL MUSEUM, ETC.

(In continuation from previous reports.)

[Fifty-fourth Congress, first session, December 2, 1895, to June 11, 1896.]

SMITHSONIAN INSTITUTION.

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the vacancy in the Board of Regents of the Smithsonian Institution, of the class other than Members of Congress, shall be filled by the appointment of William L. Wilson, of the State of West Virginia, in place of Henry Coppée, deceased. (Joint Resolution, approved January 14, 1896, Statutes of the Fifty-fourth Congress, p. 461.)

INTERNATIONAL EXCHANGES.

International Exchanges.—For expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, nineteen thousand dollars. (Sundry civil appropriation act, approved June 11, 1896, Statutes of the Fifty-fourth Congress, p. 425.)

United States Geological Survey.—For the purchase of necessary books for the library, and the payment for the transmission of public documents through the Smithsonian exchange, two thousand dollars. (Sundry civil appropriation act, approved June 11, 1896, Statutes of the Fifty-fourth Congress, p. 436.)

War Department.—For the transportation of reports and maps to foreign countries through the Smithsonian Institution, one hundred dollars. (Sundry civil appropriation act, approved June 11, 1896, Statutes of the Fifty-fourth Congress, p. 444.)

Naval Observatory.—For repairs to buildings, fixtures, and fences; furniture, gas, chemicals, and stationery; freight (including transmission of public documents through the Smithsonian exchange); foreign postage and expressage; plants, fertilizers, and all contingent expenses, two thousand five hundred dollars. (Legislative, executive, and judicial appropriation act, approved May 28, 1896, Statutes of the Fifty-fourth Congress, p. 166.)

Patent Office.—For purchase of professional and scientific books, and expenses of transporting publications of patents issued by the Patent Office to foreign governments, two thousand dollars. (Legislative, executive, and judicial appropriation act, approved May 28, 1896, Statutes of the Fifty-fourth Congress, p. 170.)

NATIONAL MUSEUM.

For cases, furniture, fixtures, and appliances required for the exhibition and safekeeping of the collections of the National Museum, including salaries or compensation of all necessary employees, fifteen thousand dollars.

For expense of heating, lighting, electrical, telegraphic, and telephonic service for the National Museum, thirteen thousand dollars.

For continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government and from other sources, including salaries or compensation of all necessary employees, one hundred and fifty-three thousand two hundred and twenty-five dollars.

For repairs to buildings, shops, and sheds, National Museum, including all necessary labor and material, four thousand dollars.

For rent of workshops for the National Museum, two thousand dollars.

For postage stamps and foreign postal cards for the National Museum, five hundred dollars.

For the erection of galleries in two or more halls of the National Museum building, said galleries to be constructed of iron beams, supported by iron pillars, and protected by iron railings, and provided with suitable staircases, the work to be done under the direction of the Architect of the Capitol, and in accordance with the approval of the Secretary of the Smithsonian Institution, eight thousand dollars. (Sundry civil appropriation act, approved June 11, 1896, Statutes of the Fifty-fourth Congress, page 425.)

Public Printing and Binding.—For the Smithsonian Institution, for printing labels and blanks, and for the "Bulletins" and annual volumes of the "Proceedings" of the National Museum, the editions of which shall not be less than three thousand copies, and binding scientific books and pamphlets presented to and acquired by the National Museum Library, twelve thousand dollars. (Sundry civil appropriation act, approved June 11, 1896, Statutes of the Fifty-fourth Congress, p. 453.)

To enable the National Museum to refund to the Honorable A. D. Straus, consul-general of the Republic of Nicaragua at New York, the amount expended by him in connection with the transportation of a collection of antique pottery to Washington city, said collection being the gift of the President of the Republic of Nicaragua to the National Museum, being for the service of the fiscal year eighteen hundred and

ninety-five, one hundred and twenty dollars. (Deficiency appropriation act, approved June 8, 1896, Statutes of the Fifty-fourth Congress, p. 279.)

NORTH AMERICAN ETHNOLOGY.

For continuing ethnological researches among the American Indians, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, forty-five thousand dollars, of which sum not exceeding one thousand dollars may be used for rent of building. (Sundry civil appropriation act, approved June 11, 1896, Statutes of the Fifty-fourth Congress, p. 425.)

Claims allowed by the Auditor of the Treasury Department.—For North American Ethnology, Smithsonian Institution, four dollars and seventy-seven cents. (Deficiency appropriation act, approved June 8, 1896, Statutes of the Fifty-fourth Congress, p. 307.)

ASTROPHYSICAL OBSERVATORY.

For maintenance of Astrophysical Observatory, under the direction of the Smithsonian Institution, including salaries of assistants, apparatus, and miscellaneous expenses, ten thousand dollars. (Sundry civil appropriation act, approved June 11, 1896, Statutes of the Fifty-fourth Congress, p. 425.

NATIONAL ZOOLOGICAL PARK.

For continuing the construction of roads, walks, bridges, water supply, sewerage, and drainage, and for grading, planting, and otherwise improving the grounds, erecting, and repairing buildings and inclosures, care, subsistence, transportation of animals, including salaries or compensation of all necessary employees, and general incidental expenses not otherwise provided for, sixty-seven thousand dollars; one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; and of the sum hereby appropriated five thousand dollars shall be used for continuing the entrance into the Zoological Park from Woodley lane, and opening driveway into Zoological Park from said entrance along the bank of Rock Creek, and five thousand dollars shall be used toward the construction of a road from the Holt Mansion entrance (on Adams Mill road) into the park to connect with the roads now in existence, including a bridge across Rock Creek. (Sundry civil appropriation act, approved June 11, 1896, Statutes of the Fifty-fourth Congress, p. 425.)

For repairs to the Holt Mansion, to make the same suitable for occupancy, and for office furniture, including the accounts set forth hereunder in House Document numbered Three hundred and twenty-four of this session, four hundred and twenty-six dollars and fifty-seven cents.

To reimburse the Smithsonian fund for assuming the expenses of labor and materials for repairs urgently necessary for the preservation of the Holt Mansion, including the accounts set forth hereunder in House Document numbered Three hundred and twenty-four of this session, four hundred and ninety-nine dollars and forty-five cents. (Deficiency appropriation act, approved June 8, 1896, Statutes of the Fifty-fourth Congress, p. 279.)

OMAHA EXPOSITION.

CHAP. 402.—An Act To authorize and encourage the holding of a transmississippi and international exposition at the city of Omaha, in the State of Nebraska, in the year eighteen hundred and ninety-eight.

Whereas it is desirable to encourage the holding of a transmississippi and international exposition at the city of Omaha, in the State of Nebraska, in the year eighteen hundred and ninety-eight, for the exhibition of the resources of the United States of America and the progress and civilization of the Western Hemisphere, and for a display of the arts, industries, manufactures, and products of the soil, mine, and sea; and

Whereas it is desirable that an exhibition shall be made of the great staples of the transmississippi region which contributes so largely to domestic and international commerce; and

Whereas encouragement should be given to an exhibit of the arts, industries, manufactures, and products, illustrative of the progress and development of that and other sections of the country; and

Whereas such exhibition should be national as well as international in its character, in which the people of this country, of Mexico, the Central and South American Governments, and other States of the world should participate, and should, therefore, have the sanction of the Congress of the United States; and

Whereas it is desirable and will be highly beneficial to bring together at such an exposition, to be held at a central position in the western part of the United States, the people of the United States and other States of this continent; and

Whereas the Transmississippi and International Exposition Association has undertaken to hold such exposition, beginning on the first day of June, eighteen hundred and ninety-eight, and closing on the first day of November, eighteen hundred and ninety-eight: Therefore,

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That a transmississippi and international exposition shall be held at the city of Omaha, in the State of Nebraska, in the year eighteen hundred and ninety-eight, under the auspices of the Transmississippi and International Exposition Association: *Provided*, That the United States shall not be liable for any of the expense attending or incident to such exposition, nor by reason of the same.

SEC. 2. That all articles which shall be imported from foreign countries for the sole purpose of exhibition at said exposition upon which there shall be a tariff or customs duty shall be admitted free of payment of duty, customs fees, or charges, under such regulation as the Secretary of the Treasury shall prescribe; but it shall be lawful at any time during the exhibition to sell for delivery at the close thereof any goods or property imported for and actually on exhibition in the exhibition building, or on the grounds, subject to such regulation for the security of the revenue and for the collection of import duties as the Secretary of the Treasury shall prescribe: *Provided*, That all such articles when sold or withdrawn for consumption in the United States shall be subject to the duty, if any, imposed upon such article by the revenue laws in force at the date of importation, and all penalties prescribed by law shall be applied and enforced against the persons who may be guilty of any illegal sale or withdrawal.

SEC. 3. That there shall be exhibited at said exposition by the Government of the United States, from its Executive Departments, the Smithsonian Institution, the United States Fish Commission, and the National Museum, such articles and material as illustrate the function and administrative faculty of the Government in time of peace, and its resources as a war power, tending to demonstrate the nature of our institutions and their adaptions to the wants of the people; and to secure a complete and harmonious arrangement of such Government exhibit a board shall be created, to be charged with the selection, preparation, arrangement, safe keeping, and exhibition of such articles and materials as the heads of the several Departments and the directors of the Smithsonian Institution and National Museum may respectively decide shall be embraced in said Government exhibit. The President may also designate additional articles for exhibition. Such board shall be composed of one person to be named by the head of each Executive Department and Museum and by the President of the United States. The President shall name the chairman of said board, and the board itself shall select such other officers as it may deem necessary.

SEC. 4. That the Secretary of the Treasury shall cause a suitable building or buildings to be erected on the site selected for the transmississippi and international exposition for the Government exhibits, and he is hereby authorized and directed to contract therefor, in the same manner and under the same regulations as for other public buildings of the United States; but the contract for said building or buildings shall not exceed the sum of fifty thousand dollars. The Secretary of the Treasury is authorized and required to dispose of such building or buildings, or the material composing the same, at the close of the exposition, giving preference to the city of Omaha, or to the said Transmississippi and International Exposition Association, to purchase the same at an appraised value to be ascertained in such manner as may be determined by the Secretary of the Treasury.

SEC. 5. The United States shall not be liable on account of said exposition for any expense incident to, or growing out of same, except for the construction of the building or buildings hereinbefore provided for, and for the purpose of paying the expense of transportation, care and custody of exhibits by the Government, and the maintenance of the said building or buildings, and the safe return of articles belonging to the said Government exhibit, and other contingent expenses to be approved by the Secretary of the Treasury upon itemized accounts and vouchers, and the total cost of said building or buildings shall not exceed the sum of fifty thousand dollars; nor shall the expenses of said Government exhibit for each and every purpose connected therewith, including the transportation of same to Omaha and from Omaha to Washington, exceed the sum of one hundred and fifty thousand dollars, amounting in all to not exceeding the sum of two hundred thousand dollars: *Provided*, That no liability against the Government shall be incurred, and no expenditure of money under this Act shall be made, until the officers of said exposition shall have furnished the Secretary of the Treasury proofs to his satisfaction that there has been obtained by said exposition corporation subscriptions of stock in good faith, contributions, donations, or appropriations from all sources for the purposes of said exposition a sum aggregating not less than two hundred and fifty thousand dollars.

SEC. 6. That the commission appointed under this Act shall not be entitled to any compensation for their services out of the Treasury of the United States, except their actual expenses for transportation and a reasonable sum to be fixed by the Secretary of the Treasury for subsistence for each day they are necessarily absent from home on the business of said commission. The officers of said commission shall receive such compensation as may be fixed by said commission, subject to the approval of the Secretary of the Treasury, which shall be paid out of the sums appropriated by Congress in aid of such exposition.

SEC. 7. That medals, with appropriate devices, emblems, and inscriptions commemorative of said transmississippi and international exposition and of the awards to be made to the exhibitors thereat, shall be prepared at some mint of the United States, for the board of directors thereof, subject to the provisions of the fifty-second section of the coinage Act of eighteen hundred and ninety-three, upon the payment of a sum not less than the cost thereof; and all the provisions, whether penal or otherwise, of said coinage Act against the counterfeiting or imitating of coins of the United States, shall apply to the medals struck and issued under this Act.

SEC. 8. That the United States shall not in any manner, nor under and circumstances, be liable for any of the acts, doings, proceedings, or representations of said Transmississippi and International Exposition Association, its officers, agents, servants, or employees, or any of them, or for service, salaries, labor, or wages of said officers, agents, serv-

ants, or employees, or any of them, or for any subscriptions to the capital stock, or for any certificates of stock, bonds, mortgages, or obligations of any kind issued by said corporation, or for any debts, liabilities, or expenses of any kind whatever attending such corporation or accruing by reason of the same.

That nothing in this Act shall be so construed as to create any liability of the United States, direct or indirect, for any debt or obligation incurred, nor for any claim for aid or pecuniary assistance from Congress or the Treasury of the United States in support or liquidation of any debts or obligations created by said commission in excess of appropriations made by Congress therefor.

(Approved, June 10, 1896, Statutes of the Fifty-fourth Congress, first session, p. 382.)

REPORT

OF

S. P. LANGLEY,

SECRETARY OF THE SMITHSONIAN INSTITUTION,

FOR THE YEAR ENDING JUNE 30, 1896.

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith a report of the operations of the Smithsonian Institution for the year ending June 30, 1896, including the work placed by Congress under its supervision in the National Museum, the Bureau of Ethnology, the Bureau of International Exchanges, the National Zoological Park, and the Astrophysical Observatory.

I have, as is customary, given briefly in the body of the report an account of the affairs of the Institution and of its bureaus for the year, reserving for the appendix the more detailed reports from those in charge of the different branches of work.

The full report upon the National Museum by the assistant secretary, Dr. G. Brown Goode, occupies a separate volume (Report of the Smithsonian Institution, National Museum, 1896).

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

The Smithsonian Establishment, as organized at the end of the fiscal year, consisted of the following ex officio members:

GROVER CLEVELAND, *President of the United States.*

ADLAI E. STEVENSON, *Vice-President of the United States.*

MELVILLE W. FULLER, *Chief Justice of the Supreme Court of the United States.*

RICHARD OLNEY, *Secretary of State.*

JOHN G. CARLISLE, *Secretary of the Treasury.*

DANIEL S. LAMONT, *Secretary of War.*

JUDSON HARMON, *Attorney-General.*

WILLIAM L. WILSON, *Postmaster-General.*

HILARY A. HERBERT, *Secretary of the Navy.*

HOKE SMITH, *Secretary of the Interior.*

J. STERLING MORTON, *Secretary of Agriculture.*

THE BOARD OF REGENTS.

In accordance with a resolution of the Board of Regents adopted January 8, 1890, by which its annual meeting occurs on the fourth Wednesday of each year, the Board met on January 22, 1896, at 10 o'clock a. m. The journal of its proceedings will be found, as hitherto, in the annual report of the Board to Congress, though reference is made later on in this report to several matters upon which action was taken at that meeting.

On December 18, 1895, Senator S. M. Cullom, of Illinois, was reappointed Regent by the President of the Senate, and on December 20, 1895, the Speaker of the House reappointed Hon. Joseph Wheeler, of Alabama, and Hon. R. R. Hitt, of Illinois, and appointed Hon. Robert Adams, jr., of Pennsylvania. Hon. William L. Wilson, of West Virginia, a former Regent, was again appointed by joint resolution of Congress, approved by the President January 14, 1896, as successor to the late Dr. Coppée.

The Board elected Hon. William L. Wilson and Hon. Gardiner G. Hubbard as members of the executive committee, with Hon. J. B. Henderson as chairman.

Formal action in memory of Dr. Coppée, who died on March 21, 1895, was taken by the Regents at the above meeting, when the following resolutions were unanimously adopted:

Whereas the members of the Board of Regents of the Smithsonian Institution are called to mourn the death of their colleague, the late Henry Coppée, LL.D., acting president of Lehigh University, for twenty years a Regent of the Institution, and long a member of its executive committee:

Resolved, That the Board of Regents feel sincere sorrow in the loss of one whose distinguished career as a soldier, a man of letters, and whose services in the promotion of education command their highest respect and admiration.

Resolved, That in the death of Dr. Coppée the Smithsonian Institution and the Board of Regents have suffered the loss of a tried and valued friend, a wise and prudent counsellor, whose genial courtesy, well-stored, disciplined mind, and sincere devotion to the interests of the Institution will be ever remembered.

Resolved, That these resolutions be recorded in the Journal of the Proceedings of the Board, and that the Secretary be requested to send a copy to the family of their departed associate and friend, in token of sympathy in this common affliction.

ADMINISTRATION.

I have already remarked that the expenses borne by the Institution incidental to its administration of Government trusts are not specifically provided for by any of the present appropriations, and that I deemed it in the interest of economy that an appropriation be asked to cover these items, which can not be done under their present terms, but no decisive action has as yet been taken in this matter.

On June 16 the President of the United States directed that the classified civil service be extended to include the several bureaus of the Smithsonian Institution, and in accordance therewith the employees of the National Museum, Zoological Park, Bureau of Exchanges, Bureau of Ethnology, and Astrophysical Observatory were, on June 30, 1896, made subject to the civil service rules.

FINANCES.

The permanent funds of the Institution are as follows:

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposits from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposits from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Portion of residuary legacy, T. G. Hodgkins, 1894		8,000.00
Total permanent fund		912,000.00

The Regents also hold certain approved railroad bonds, forming a part of the fund established by Mr. Hodgkins for investigations of the properties of atmospheric air.

By act of Congress approved by the President March 12, 1894, an amendment was made to section 5591 of the Revised Statutes, the fundamental act organizing the Institution, as follows:

The Secretary of the Treasury is authorized and directed to receive into the Treasury, on the same terms as the original bequest of James Smithson, such sums as the Regents may, from time to time, see fit to deposit, not exceeding, with the original bequest, the sum of $1,000,000: *Provided*, That this shall not operate as a limitation on the power of the Smithsonian Institution to receive money or other property by gift, bequest, or devise, and to hold and dispose of the same in promotion of the purposes thereof.

Under this section 5591 of the Revised Statutes, modified as above noted, the fund of $912,000 is deposited in the Treasury of the United States, bearing interest at 6 per cent per annum, the interest alone being used in carrying out the aims of the Institution.

At the beginning of the fiscal year July 1, 1895, the unexpended balance from the income and from other sources, as stated in my report for last year, was $63,001.74. Interest on the permanent fund in the Treasury and elsewhere, amounting to $56,395, was received during the year, which, together with a sum of $6,474.61 received from the sale of publications and from miscellaneous sources, made the total receipts $62,869.61.

The entire expenditures during the year, including $11,000 paid for prizes awarded from the Hodgkins fund, in accordance with the recommendation of the award committee, and referred to in my last report,

amounted to $68,805.57, for the details of which reference is made to the report of the executive committee. On June 30, 1896, the balance in the Treasury of the United States to the credit of the Secretary for the expenses of the Institution was $57,065.78, which includes the sum of $10,000 referred to in previous reports, $5,000 received from the estate of Dr. J. H. Kidder, and a like sum from Dr. Alexander Graham Bell, the latter a gift made personally to the Secretary to promote certain physical researches. This latter sum was, with the donor's consent, deposited by the Secretary to the credit of the current funds of the Institution.

This balance also includes the interest accumulated on the Hodgkins donation, which is held against certain contingent obligations, besides relatively considerable sums held to meet obligations which may be expected to mature as the result of different scientific investigations or publications in progress.

The Institution has been charged with the disbursement, during the fiscal year 1895–96, of the following appropriations:

For International Exchanges	$17,000
For North American Ethnology	40,000
For fire protection, Smithsonian Institution and National Museum	800
For United States National Museum:	
Preservation of collections	143,225
Furniture and fixtures	12,500
Heating and lighting	13,000
Postage	500
Repairs to building	4,000
Rent of workshops	900
For National Zoological Park	55,000
For entrance and driveway, Zoological Park, District Columbia	5,000
For Astrophysical Observatory	9,000

All the vouchers and checks for the disbursements have been examined by the executive committee, and the expenditures will be found reported in accordance with the provisions of the sundry civil acts of October 2, 1888, and August 5, 1892, in a letter addressed to the Speaker of the House of Representatives.

The vouchers for all the expenditures from the Smithsonian fund proper have been likewise examined, and their correctness certified to by the executive committee, whose statement will be published, together with the accounts of the funds appropriated by Congress, in that committee's report.

The estimates for the fiscal year ending June 30, 1897, for carrying on the Government interests under the charge of the Smithsonian Institution, and forwarded as usual to the Secretary of the Treasury, were as follows:

International exchanges	$23,000
North American Ethnology	50,000
National Museum:	
Preservation of collections	180,000
Furniture and fixtures	30,000

National Museum—Continued.

Heating and lighting	$15,000
Postage	500
Galleries	8,000
Repairs to building	8,000
Rent of workshops	2,000
National Zoological Park	75,000
Astrophysical Observatory	10,000

BUILDINGS.

The crowded condition of the National Museum will be somewhat relieved by the addition of galleries provided for under an appropriation of $8,000 made by the last Congress, but there is still an extremely urgent need for a new building, as stated more fully on a subsequent page. There was also granted an additional appropriation for rent of storage rooms and workshops for the Museum.

RESEARCH.

The time of the Secretary is almost wholly given to administrative duties, although in the original plan of the Institution he was expected by the Regents to personally contribute to the advancement of knowledge.[1] The Secretary has continued to give what opportunities he could spare from the administrative duties and what he could contribute from his private hours to the investigations which have already been referred to in previous reports.

The first of these, upon the solar spectrum, has been carried on at the Astrophysical Observatory, and to this reference is made more at length in another part of this report.

The second, beginning as an investigation of certain physical data of aerodynamics, has arrived at an important stage in its development.

The possibility of mechanical flight was, until a comparatively few years ago, considered a visionary one by most men of science. The writer, who was led to an opposite conclusion, and who had commenced experiments before he became connected with the Institution, published under its auspices in 1891 a treatise entitled "Experiments in aerodynamics," which gave the results of direct experiment on the pressure of the air on inclined surfaces, showing that rules hitherto relied on, partly on the faith of the great name of Sir Isaac Newton, were not in fact supported by a direct study of nature. These new experiments gave evidence that mechanical flight—that is, not of balloons, but of bodies heavier than air, impelled and supported by power—was at least theoretically possible. This, however, was not saying that such machines could be launched into the air and made to continue a horizontal course or to descend to the ground with safety, matters to be determined by trial and further experiment.

[1] *Resolved,* That the Secretary continue his researches in physical science, and present such facts and principles as may be developed, for publication in the Smithsonian Contributions. Adopted at meeting of the Board of Regents, January 26, 1847.

The writer has, during the intervals of his official duties, continued to experiment in this manner, until he has reached a measure of success which seems to justify him in making the statement here that mechanical flight has now been attained.

On the 6th of May last a mechanism built chiefly of steel and driven by a steam engine made two flights each of over half a mile.[1] In each case the process was wholly mechanical, there being no support from gas, but on the contrary the machine being a thousand or more times heavier than the air in which it was made to move. Of the first of these flights I beg to give a statement by an eyewitness, Mr. Alexander Graham Bell, which was communicated in French to the Académie des Sciences of the Institut de France, and which appeared as follows in Nature:

EXPERIMENTS IN MECHANICAL FLIGHT.

I have been for some years engaged in investigations connected with aerodromic problems, and particularly with the theoretical conditions of mechanical flight. A portion of these have been published by me under the titles, "Experiments in aerodynamics" and "The internal work of the wind," but I have not hitherto at any time described any actual trials in artificial flight.

With regard to the latter, I have desired to experiment until I reached a solution of the mechanical difficulties of the problem, which consist, it must be understood, not only in sustaining a heavy body in the air by mechanical means (although this difficulty is alone great), but also in the automatic direction of it in a horizontal and rectilinear course. These difficulties have so delayed the work that in view of the demands upon my time, which render it uncertain how far I can personally conduct these experiments to the complete conclusion I seek, I have been led to authorize some account of the degree of success which has actually been attained, more particularly at the kind request of my friend, Mr. Alexander Graham Bell, who has shown me a letter which he will communicate to you. In acceding to his wish, and while I do not at present desire to enter into details, let me add that the aerodrome, or "flying machine" in question, is built chiefly of steel, and that it is not supported by any gas, or by any means but by its steam engine. This is of between 1 and 2 horsepower, and it weighs, including fire grate, boilers, and every moving part, less than 7 pounds. This engine is employed in turning aerial propellers which move the aerodrome forward, so that it is sustained by the reaction of the air under its supporting surfaces.

I should, in further explanation of what Mr. Bell has said, add that owing to the small scale of construction no means have been provided for condensing the steam after it has passed through the engine, and that, owing to the consequent waste of water, the aerodrome has no means of sustaining itself in the air for more than a very short time—a difficulty which does not present itself in a larger construction, where the water can be condensed and used over again. The flights described, therefore, were necessarily brief.

S. P. LANGLEY.

Through the courtesy of Mr. S. P. Langley, Secretary of the Smithsonian Institution, I have had on various occasions the privilege of witnessing his experiments with aerodromes, and especially the remarkable success attained by him in experiments, made on the Potomac River on Wednesday, May 6, which led me to urge him to make public some of these results.

I had the pleasure of witnessing the successful flight of some of these aerodromes more than a year ago, but Professor Langley's reluctance to make the results public

[1] Since the preparation of this report this result has been nearly doubled.

at that time prevented me from asking him, as I have done since, to let me give an account of what I saw.

On the date named, two ascensions were made by the aerodrome, or so-called "flying machine," which I will not describe here further than to say that it appeared to me to be built almost entirely of metal, and driven by a steam engine which I have understood was carrying fuel and a water supply for a very brief period, and which was of extraordinary lightness.

The absolute weight of the aerodrome, including that of the engine and all appurtenances, was, as I was told, about 25 pounds, and the distance, from tip to tip, of the supporting surfaces was, as I observed, about 12 or 14 feet.

The method of propulsion was by aerial screw propellers, and there was no gas or other aid for lifting it in the air except its own internal energy.

On the occasion referred to, the aerodrome, at a given signal, started from a platform about 20 feet above the water, and rose at first directly in the face of the wind, moving at all times with remarkable steadiness, and subsequently swinging around in large curves of, perhaps, a hundred yards in diameter, and continually ascending until its steam was exhausted, when, at a lapse of about a minute and a half, and at a height which I judged to be between 80 and 100 feet in the air, the wheels ceased turning, and the machine, deprived of the aid of its propellers, to my surprise did not fall, but settled down so softly and gently that it touched the water without the least shock, and was in fact immediately ready for another trial.

In the second trial, which followed directly, it repeated in nearly every respect the actions of the first, except that the direction of its course was different. It ascended again in the face of the wind, afterwards moving steadily and continually in large curves accompanied with a rising motion and a lateral advance. Its motion was, in fact, so steady that I think a glass of water on its surface would have remained unspilled. When the steam gave out again, it repeated for a second time the experience of the first trial when the steam had ceased, and settled gently and easily down. What height it reached at this trial I can not say, as I was not so favorably placed as in the first; but I had occasion to notice that this time its course took it over a wooded promontory, and I was relieved of some apprehension in seeing that it was already so high as to pass the tree tops by 20 or 30 feet. It reached the water one minute and thirty-one seconds from the time it started, at a measured distance of over 900 feet from the point at which it rose.

This, however, was by no means the length of its flight. I estimated from the diameter of the curve described, from the number of turns of the propellers as given by the automatic counter, after due allowance for slip, and from other measures, that the actual length of flight on each occasion was slightly over 3,000 feet. It is at least safe to say that each exceeded half an English mile.

From the time and distance it will be noticed that the velocity was between 20 and 25 miles an hour, in a course which was constantly taking it "up hill." I may add that on a previous occasion I have seen a far higher velocity attained by the same aerodrome when its course was horizontal.

I have no desire to enter into detail further than I have done, but I can not but add that it seems to me that no one who was present on this interesting occasion could have failed to recognize that the practicability of mechanical flight had been demonstrated.

ALEXANDER GRAHAM BELL.

I do not know how far interest in this work may bias my judgment, but it appears to me that in these things, whose final accomplishment has come under the charge of the Smithsonian Institution, it has made a contribution to the utilities of the world which will be memorable.

The results of Prof. E. W. Morley's investigations on the density of oxygen and hydrogen, referred to at length in my last report, have been

printed, as have also those of Drs. Billings and Mitchell. The valuable researches of the latter gentlemen are being continued under an additional grant.

The subscription for the Astronomical Journal has been continued.

EXPLORATIONS.

The Institution has continued to carry on ethnological and natural history explorations during the year, to which reference is made in the reports of the Bureau of Ethnology. I may call special attention to the explorations among the cliff dwellings of Arizona by Dr. Fewkes, and in the territory of the Seri Indians in Mexico by Mr. McGee, as also on the western coast of Florida by F. H. Cushing, where abundant relics of the prehistoric age were discovered. Dr. William L. Abbott has continued his contributions of natural history and ethnological specimens collected by him in Africa and Asia.

PUBLICATIONS.

The publications of the Institution include the Contributions to Knowledge, the Miscellaneous Collections, and the Annual Reports, the first two being printed at the expense of the Institution, while the reports are Government documents. Various publications are also issued by the National Museum and the Bureau of Ethnology, to which allusion is elsewhere made.

Contributions to Knowledge.—Three volumes of the Contributions were completed during the year, and two separate memoirs. Volumes XXX and XXXI were the text and plates of an exhaustive illustrated work by Dr. G. Brown Goode and Dr. Tarleton H. Bean, entitled "Oceanic ichthyology," being a treatise on the deep-sea and pelagic fishes of the world.

Volume XXXII, on "Life histories of North American birds, parrots to grackles," by Maj. Charles Bendire, U. S. A., is a second contribution on this subject, the first volume, including gallinaceous birds, pigeons or doves, and birds of prey, having been published by the Institution several years ago.

The memoir by Prof. E. W. Morley on the density of oxygen and hydrogen was published early in the year in a volume of 117 pages, and has been reprinted in full in Zeitschrift fur Physikalische Chemie, a duplicate set of blocks of the illustrations having been sent to the publishers at their request. In this memoir Professor Morley describes in detail the methods employed in his investigations and illustrates the apparatus employed. The atomic weight of oxygen was studied by two methods: (1) The synthesis of water, in which he achieved completeness by actually weighing the hydrogen, the oxygen, and the water formed; and (2) by the density ratio between oxygen and hydrogen. By both methods he reached the same result: $O=15.879$, with variation in the *fourth* decimal place as between the two.

The results of the investigation by Drs. Billings, Mitchell, and

Bergey on the composition of expired air was published as a memoir in the Contributions, forming a volume of 81 pages.

Two memoirs submitted in competition for the Hodgkins fund prizes were in press but not ready for distribution at the close of the year. One of these was by Lord Rayleigh and Professor Ramsay announcing the discovery of argon and describing the methods of the investigation leading to their discovery of that new element of the atmosphere. For this achievement the authors were awarded the first prize of $10,000.

The second memoir was on atmospheric actinometry, by Prof. Emile Duclaux, for which the author was awarded honorable mention.

Miscellaneous Collections.—In this series two works were completed and four put to press during the fiscal year. The completed publications were Part II of the Index of the Genera and Species of the Foraminifera, by Charles Davies Sherborn, and a revised edition of the Smithsonian Meteorological Tables. The publications in press are the Smithsonian Physical Tables, by Prof. Thomas Gray; an illustrated description of the Mountain Observatories of the World, by Prof. E. S. Holden; a paper by Dr. D. H. Bergey, on Methods of Determination of Organic Matter in Air, and an exhaustive Catalogue of Scientific and Technical Periodicals of the World, from 1665 to 1895, compiled by Dr. Bolton.

The prize essay on "Air and life," by Dr. Varigny, as also some of the other essays submitted in the Hodgkins prize competition, have been put to press and will be issued during the next year.

There is also in preparation a supplement to Bolton's Bibliography of Chemistry, an Index of Mineral Springs of the World, by Professor Tuckerman, and a recalculation of atomic weights, by Prof. F. W. Clarke.

The usual separate edition has been issued of the several papers in the General Appendix of the Annual Report.

Annual Reports.—The Smithsonian Annual Report is in two volumes, the first devoted to the Institution proper and the second relating to the National Museum. The General Appendix of Part I consists of selected memoirs which have for the most part already appeared elsewhere, but which are of such special interest and permanent value as to appear worthy of republication by the Institution in the "increase and diffusion of knowledge among men."

The report for 1894 was delivered by the printer after the close of the fiscal year and some progress had been made on the report for 1895.

Proceedings and bulletin of the National Museum.—The publications of the Museum are mentioned in Appendix I, and need not be referred to here further than to say that the several papers of volume 18 of the Proceedings were published in pamphlet form, and that Bulletin 47, on the Fishes of North and Middle America, by Dr. Jordan and Professor Evermann, were nearly ready for distribution.

Bureau of Ethnology publications.—The Thirteenth Annual Report of the Bureau of Ethnology was distributed during the year, and the

manuscript of the fourteenth, fifteenth, and sixteenth reports had been transmitted to the Public Printer.

LIBRARY.

In my last report I pointed out that the lists prepared in accordance with the plans formulated by the Secretary, detailed in my report for 1887–88, had all been written for.

In further continuance of this work, which is never ending, I have accordingly employed the new manuscript list of the learned societies of the world in the Bureau of International Exchanges. Letters have been written with the gratifying result that 299 new exchanges were entered into, and 155 defective series were entirely or partially completed.

It has been the policy of the Institution from its inception to endeavor to have as complete a set as possible of the transactions of learned societies and periodicals, and it is my desire that this collection should continue to be as complete as the resources of the Institution render possible.

The project of the Royal Society for the preparing of a bibliography of science, beginning with the year 1900, referred to in my report for 1895, resulted in the calling by the British Government of a bibliographical conference in London in July, 1896. An invitation to send delegates to the conference was extended to the United States, along with the other nations which it was presumed were interested.

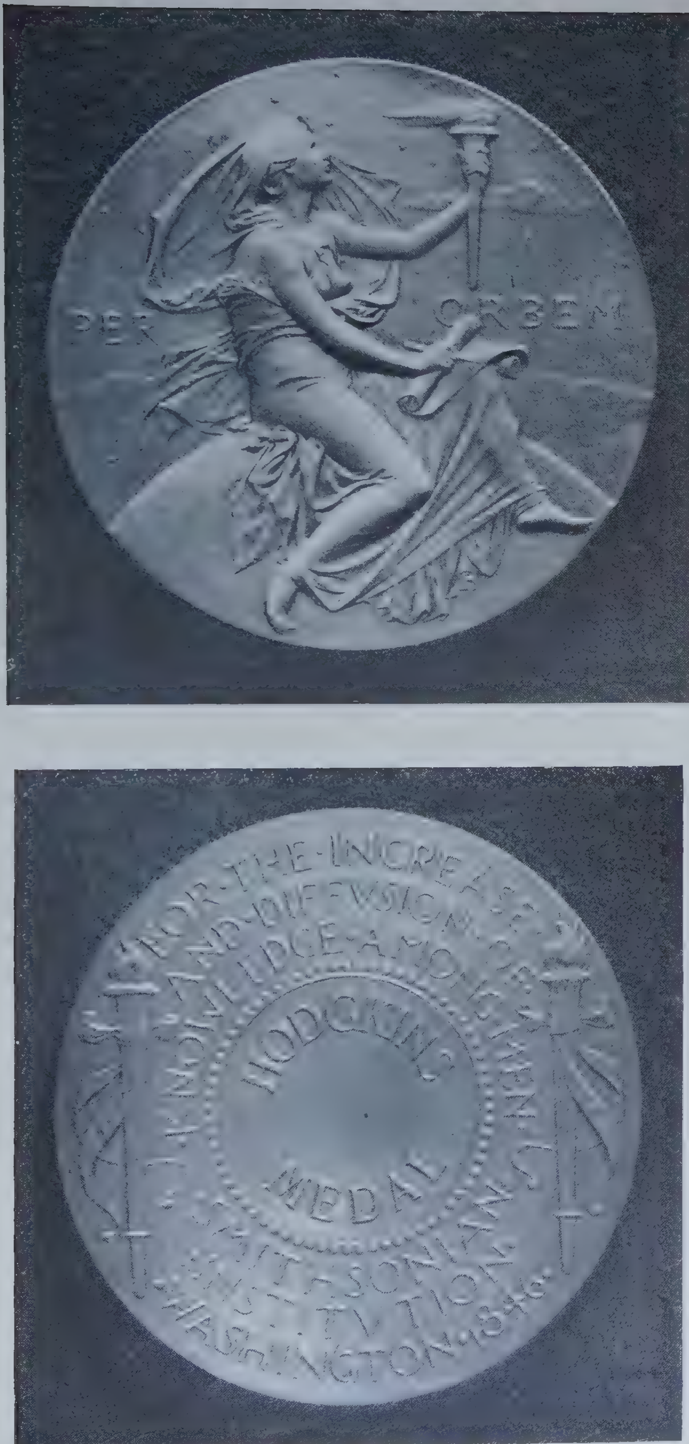
The matter having been referred to me by the Secretary of State, I had much pleasure in suggesting that the United States participate in the conference, and in recommending Dr. John S. Billings, United States Army, retired, director of the New York Public Library, and Prof. Simon Newcomb, United States Navy, Superintendent of the Nautical Almanac, as the delegates on behalf of the United States. There is reason to hope that most fruitful results will proceed from this conference.

The revised edition of the Catalogue of Scientific and Technical Periodicals (1665–1882), published by the Institution in 1885, which I stated in my last report was being brought down to 1895, is now completed and in the hands of the printer. It is expected that it will be issued during the course of the coming year. Like the first edition, it has been prepared under the direction of Dr. H. C. Bolton.

It is confidently expected that the new building of the Library of Congress will be completed during the coming year, and that adequate provision will be made for the reception of the Smithsonian deposit, and a special reading room provided.

HODGKINS FUND.

As stated in my last report, the prizes offered by the Institution for important discoveries in connection with the composition of atmos-



Hodgkins Medal of the Smithsonian Institution.

pheric air, and for essays on the air in relation to human life and health, resulted in the award of the first prize of $10,000 to Lord Rayleigh and Prof. William Ramsay for their discovery of argon, a new element of the atmosphere. The prize of $1,000 for the best popular essay was awarded to Dr. Henry de Varigny, of Paris, for his essay on "Air and life."

Six of the papers submitted in competition for the prizes were awarded honorable mention, together with medals, as announced in my last report. The design for the medal is by M. J. C. Chaplain, of Paris, a member of the French Academy and one of the most eminent medalists of the world. The obverse bears a female figure carrying a torch in her left hand and in her right a scroll, emblematic of Knowledge, and the words "Per orbem." The reverse is adapted from the seal of the Institution, designed by St. Gaudens, the map of the world being replaced by the words "Hodgkins medal," as is shown in the accompanying illustrations, which are the size of the original. The medals were struck at the Paris mint.

Dr. J. S. Billings and Dr. S. Weir Mitchell having completed their investigations on the composition of expired air and its effects on animal life, their report has been published as a Memoir of the Contributions to Knowledge. The investigators found that the air in inhabited rooms, such as the hospital ward in which experiments were made, is contaminated from many sources besides the expired air of the occupants, and that the most important of these contaminations are in the form of minute particles or dusts, in which there are micro-organisms, including some of the bacteria which produce inflammatory and suppurative disorders. It is probable that these dust particles are the only really dangerous elements in the air, and the important conclusion is reached that it appears improbable that there is any peculiar volatile poisonous matter in the air expired by healthy men and animals other than carbonic acid.

An additional grant has been made to Drs. Billings and Mitchell to continue other lines of investigation, especially whether the long-continued breathing of air rendered impure by respiration or by volatile exhalations from the skin and mucous membranes increases the susceptibility to infection by certain micro-organisms, especially those which are now considered to be the specific causes of consumption and croupous pneumonia, the diseases which are most fatal in crowded and ill-ventilated rooms.

THE AVERY FUND.

The property devised to the Institution by the late Robert Stanton Avery, of Washington City, consists of lots on Capitol Hill, some improved by dwelling houses, and certain personal property, chiefly represented by securities of the Northern Pacific Railroad Company.

The real estate is of an assessed District valuation of $28,931, and the personal property, at its present market quotation, and after

deducting a legacy to Miss Julia N. Avery, is estimated to be valued at between $6,000 and $7,000.

SMITHSONIAN HALF-CENTURY MEMORIAL.

The act of Congress establishing the Smithsonian Institution was signed by President Polk, August 10, 1846, and the first meeting of the Board of Regents was held on September 7 of that year. In view of the completion of the first half century, I discussed with the executive committee, as far back as 1893, the best method of celebrating this event. It seemed quite impracticable to arrange for a gathering of delegates from other scientific institutions, such as is often held on similar occasions by universities and academies of science. The simplest and most effective means of commemorating the event appeared to be the publication of a suitable memorial volume, which should give an account of the institution, its history, its achievements, and its present condition.

The late Dr. G. Brown Goode, whose acquaintance with the history of the Institution was unrivaled, drew up a comprehensive plan for the volume. This plan being settled upon, Dr. James C. Welling, having at that time just retired from the presidency of Columbian University, agreed to undertake the editorial supervision of the volume. His death seemed to put a stop to the proposed work, for there appeared to be no one sufficiently acquainted with the history of the Institution who had the ability, the willingness, and the leisure to undertake this very considerable task. It was then that Dr. Goode told me of his great desire to undertake the work. Knowing how numerous his duties already were, I at first refused, and it was only at his earnest solicitation that I agreed to his editorial supervision of the volume.

At the time of his death the manuscript was so far advanced as to render possible its completion for the press and publication upon the lines he laid down. He had not only written many of the chapters himself and made arrangements for the illustrations, but had almost settled with the printers, as to the style of the type and form of the page, and other details of the book. While its appearance has been slightly delayed, I feel able to say that the volume will be published early in 1897, and it is sufficiently advanced to allow the statement that the editorial work is Dr. Goode's, and to express the confidence that it will be found as worthy of the Institution as was every other task ever intrusted to his hands.

The volume will be a royal octavo of about 750 pages and will be printed from type in an edition of 2,000, with 250 additional copies on hand made paper. The scope of Part I is indicated by the following chapters:

The Founder, James Smithson, by Mr. S. P. Langley.
The acceptance of the Smithson Bequest by the United States, by Mr. G. Brown Goode.

The Establishment and the Regents, by Mr. Goode; and list of Regents with brief biographical notices, by Mr. W. J. Rhees.
The Secretaries, by Mr. Goode.
The Benefactors of the Institution, by Mr. Langley.
Buildings and grounds, by Mr. Goode.
The Smithsonian Library, by Mr. Cyrus Adler.
The National Museum, by Mr. F. W. True.
The Bureau of Ethnology, by Mr. W J McGee.
The Bureau of Exchanges, by Mr. W. C. Winlock.
The Astrophysical Observatory, by Mr. Langley.
The Zoological Park, by Dr. Frank Baker.
Expeditions and explorations, by Mr. F. W. True.
The Smithsonian publications, by Mr. Cyrus Adler.

I have now decided to add to this another chapter, being the biography of the late Dr. Goode, by Dr. David Starr Jordan, president of Leland Stanford, Junior, University.

The second part of the book, which may be described as appreciations of the work of the Institution in different departments of science, is almost entirely written by gentlemen not connected with the Institution. The chapters are as follows:

1. Physics, by T. C. Mendenhall, president of the Worcester Polytechnic Institute, Worcester, Mass.
2. Mathematics, Robert Simpson Woodward, professor of mechanics, Columbia University, New York City.
3. Astronomy and Astrophysics, by Edward S. Holden, director of the Lick Observatory, Mount Hamilton, Cal.
4. Chemistry, by Dr. Marcus Benjamin, United States National Museum.
5. Geology and Mineralogy, by William N. Rice, professor of geology, Wesleyan University, Middletown, Conn.
6. Meteorology, by Dr. Marcus Benjamin.
7. Paleontology, by Edward D. Cope, professor of zoology and comparative anatomy, University of Pennsylvania, Philadelphia, and editor of the American Naturalist.
8. Botany, by William G. Farlow, professor of cryptogamic botany, Harvard University, Cambridge, Mass.
9. Zoology, by Dr. Theodore N. Gill, professor of zoology, Columbian University, Washington.
10. Ethnology and archæology, by Dr. J. Walter Fewkes, late director of the Hemenway Expedition.
11. Geography, by Gardiner G. Hubbard, president of the National Geographic Society, Washington.
12. Bibliography, by Dr. H. Carrington Bolton.
13. Cooperation of the Smithsonian Institution with other institutions of learning, by Daniel Coit Gilman, president of Johns Hopkins University, Baltimore, Md.
14. The influence of the Smithsonian Institution upon the development of libraries, the organization of the work of societies, and the publication of scientific literature in the United States, by Dr. John S. Billings, director of the New York Public Library.
15. Relations between the Smithsonian Institution and the Library of Congress, by Ainsworth R. Spofford, Librarian of Congress.

The illustrations will consist of copies of the two known portraits of James Smithson and a representation of the memorial tablet erected at

Genoa; also portraits of the Chancellors (Dallas, Fillmore, Taney, Chase, Waite, and Fuller), the Secretaries, of Mr. Hodgkins, and of certain of the earlier Regents who were especially influential in shaping the character of the Institution during its early days (John Quincy Adams, Robert Dale Owen, Richard Rush, Louis Agassiz, George Bancroft, William T. Sherman, Asa Gray, and J. C. Welling), with views of the Institution and illustrations of its seal and of the Hodgkins medal.

CORRESPONDENCE.

In addition to the very voluminous routine and business correspondence of the National Museum, or special correspondence of the Bureau of Ethnology, of the Zoological Park, and of the Bureau of Exchanges, a constantly increasing number of letters come directly to the Secretary's office from all parts of the country, on every imaginable subject that can by any possibility be supposed to have a relation to science. Requests for statistics that may be of great value and importance to the writer, inquiries from teachers and others, are constantly received, and it is still my aim that this correspondence shall receive the same careful attention that was bestowed upon it in the early days of the Institution, when the number of letters formed but a small fraction of those received at present; but it will be understood that the fulfillment of this aim grows increasingly difficult. An effort is made to give a full reply to all such inquiries, often involving a large amount of labor on the part of the curators, as well as of those immediately occupied with the correspondence of the Institution, out of proportion to the merits of the case.

Of the more important correspondence of the Secretary's office, 3,788 entries were made in the registry book of letters received during the year, while double that number of letters were received and referred to the different bureaus of the Institution in the same time.

The card index of letters received and written is now complete from January 1, 1892, to the present day, constituting the current file. The correspondence prior to the current file has been placed in the archives, and the index to the files is now practically complete.

MISCELLANEOUS.

Naples tables.—The Institution has renewed for three years the lease of the Smithsonian Table at the Naples Zoological Station, and the facilities thus afforded have proved of value to the investigators who have carried on biological studies there during the year. Dr. J. S. Billings, U. S. A., Dr. E. B. Wilson, Dr. C. W. Stiles, and Dr. Harrison Allen have continued valuable aid in examining the testimonials of applicants for the occupancy of the Naples table, as well as in the consideration of various questions in connection with the assignment of the table, to which I have asked attention.

Among the numerous additional applications for occupancy of the

table the following have been favorably acted upon: W. T. Swingle, B. Sc., Kansas State Agricultural College, 1890, assistant pathologist, United States Department of Agriculture, appointed for two months in the winter of 1895–96; and F. M. McFarland, professor of biology and geology, Olivet College, Michigan, assistant professor of histology, Leland Stanford Junior University, appointed for three months during the spring and summer of 1896. Prof. L. Murbach, who occupied the table for two months in 1894, has submitted a memoir entitled "Observations on the development and migration of the urticating organs of sea nettles, Cnidaria," which has been published in the Proceedings of the United States National Museum.

The table has been occupied constantly since October 1, 1893, the date of the first appointment, with the exception of May, 1894. In several instances Dr. Dohrn, the director of the station, has courteously arranged for the accommodation of two occupants at the same time.

In order that all investigators may be given an equal opportunity to avail themselves of the facilities for study at Naples, final action upon applications is not taken more than six months in advance of the date for which the table is desired, and when more than one application is filed for the same period, presumably of equal merit, the assignment is made according to priority of application. No appointment is made for a period of more than six months.

Art collection.—The fundamental act creating the Institution, in enumerating its functions, apparently considers it first as a kind of gallery of art, and declares that all objects of art and of foreign and curious research the property of the United States shall be delivered to the Regents, and only after this adds that objects of natural history shall be so, also.

The scientific side of the Institution's activities has been in the past so much greater than its æsthetic that it is well to recall the fact that it was intended by Congress to be a curator of the national art, and that this function has never been forgotten, though often in abeyance.

In 1849 Secretary Henry, in pursuance of this function of an institution which in his own words existed for "the true, the beautiful, as well as for the immediately practical," purchased of the Hon. George P. Marsh a collection of works of art, chiefly engravings, of much artistic merit and now of great commercial value. A portion of this collection was some years ago deposited in the Corcoran Gallery of Art and in the Library of Congress, subject to recall by the Regents at any time. In accordance with the terms of the deposit some of these objects have already been returned to the Institution.

A collection of etchings and engravings was during the past year presented to the Institution by Mr. Charles William Sherborn, of London.

Atlanta Exposition.—Under the provisions of an appropriation made by Congress for a Government exhibit at the Cotton States and International Exposition at Atlanta, during the autumn of 1895, a very

satisfactory exhibit was prepared, illustrating every phase of the activities of the Institution and its bureaus, especially the National Museum. A detailed description will be printed in the Museum Report for 1896.

Zoological congress.—Dr. Charles W. Stiles, honorary curator in the National Museum, was nominated by me, and appointed by the Secretary of State, as United States representative at the International Zoological Congress at Leyden, Holland, in September, 1895, and Dr. Herbert Haviland Field was appointed as a second delegate to the same congress. Dr. Stiles reports that 232 members attended the congress, representing 22 nationalities. The business of greatest international importance accomplished was the adoption of resolutions (1) establishing a central bureau of bibliography for zoology, (2) appointing an international commission upon the code of nomenclature, and (3) in favor of the repeal of the section of the present international postal laws which prohibits the sending of "animals living or dead" through the international mails. Committees were appointed in accordance with the provisions of these resolutions.

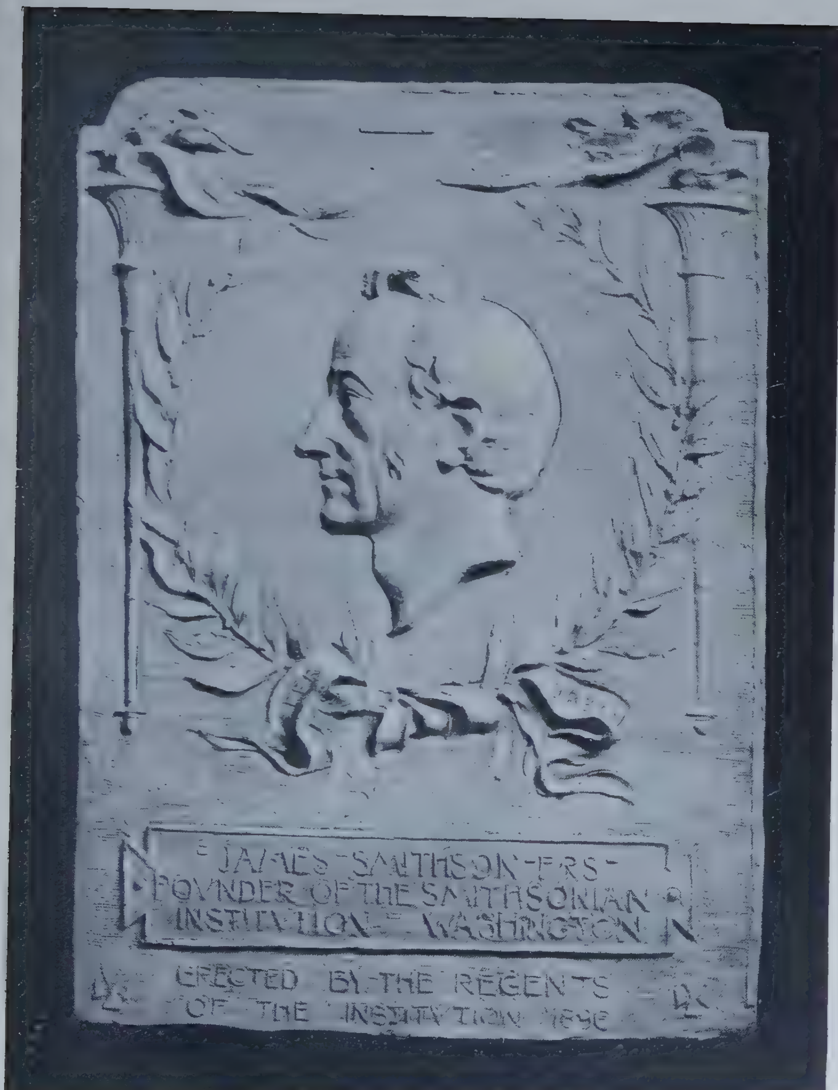
The Smithson Memorial tablets.—The bronze tablets mentioned in my last report have been completed and will be placed on Smithson's tomb and in the English church at Genoa, in memory of the founder of the Smithsonian Institution. The tablets, which measure 40 by 28 inches, were designed by Mr. William Ordway Partridge, of New York City. They bear a portrait of James Smithson, surrounded by a wreath and on either side a torch, and beneath is the legend "James Smithson, F. R. S., founder of the Smithsonian Institution, Washington; erected by the Regents of the Institution, 1896." The accompanying illustration of the tablets is from a photograph of the plaster model.

American Historical Association.—The annual report of the American Historical Association for the year 1895 was transmitted to Congress through the Secretary of the Institution, in accordance with the act of incorporation of the association. These reports are Congressional documents, and the Institution has had no control of their distribution.

NATIONAL MUSEUM.

The museum of the Smithsonian Institution, which was formed in part and for a time entirely maintained at the expense of the Smithson fund, was the nucleus of the present National Museum, to which the Regents have continued to contribute matter especially under their charge, so that the Institution has in it a large pecuniary interest, and has always maintained with it, on account of this history and ownership, relationships of a more intimate kind than with some bureaus which have not been at one time a part of itself.

Ever since 1858 Congress has appropriated money for the maintenance of the Museum, but it has scarcely made any special appropriation for the improvement of the collections by purchase, so that in respect



THE SMITHSON MEMORIAL TABLET.

to the means at disposal for this it has been almost at the foot of all American museums, being surpassed by every municipal museum of note.

In the earlier years of the Museum this was not of very great moment, as numerous American natural-history specimens came in from the various Government expeditions. It became evident later that for a proper understanding of native products it was necessary to compare them with those of other parts of the world. To obtain these exotic specimens no adequate means have ever been provided, and it is not to be expected that valuable, specially-selected specimens from foreign lands will ever be procured in large numbers except by purchase or by the sending out of expeditions.

The result of years of accumulation unsupported by purchases has been that the collections of the National Museum are very unsymmetrical—full and rich in some directions, especially in North American natural history, surpassing all other museums, and exceedingly poor in others.

In the meanwhile museums have sprung up in some of the large cities of the United States, with liberal means for the acquisition of specimens by purchase and the sending out of expeditions, and these are outstripping the National Museum in many of its departments by the wealth of their collections.

From such causes the National Museum, while truly national in the sense of possessing very full collections of the natural products of the United States, maintains, with increasing difficulty, its supremacy in this special respect over the wealthier private museums, and compares very unfavorably, as regards the breadth of its collections, with the national museums of Europe—in London, Paris, Berlin, St. Petersburg, Vienna, and Florence.

I called attention to this matter in a former report when I remarked that the American Museum of Natural History in New York expended $23,552.89, in 1892, for filling out its natural-history collections alone, while the National Museum in the fiscal year 1892–93 expended only $5,769.75 for specimens of all kinds.

The discrepancy has grown greater in succeeding years. In the past fiscal year, for example, the National Museum expended $3,336 for all collections, while the expenditures of the American Museum of Natural History, for acquiring natural-history collections alone, were $41,959.65, or fully thirteen times as much as expended by the National Museum, although the total amount of money available for the two was not greatly different, that for the National Museum being in fact the larger.

The causes of this discrepancy are not far to seek. The income of the local museum is usually devotable wholly to its collections (which in the case cited are housed in adequate buildings) and to their increase and care, which include the services of officers and employees in charge of them and who are devoted only to them.

Congress has laid upon the National Museum quite other and additional functions. Not to dwell upon the fact (so constantly insisted on in previous reports) of the entire inadequacy of the buildings here for the collections, the National Museum, containing all the diverse collections of the Government, has many more departments and a very much larger necessary expenditure for salaries, owing to the diversity of its cares. It is also the source of supply which has been successively depleted for the exhibitions at Louisville, Cincinnati, and New Orleans in 1884 and 1885, Madrid in 1892, Chicago in 1893, and Atlanta in 1895; and a large part of the force has thus been engaged in the disarrangement of its own collections, a condition of things under which no museum, public or private, could prosper.

It is also called upon by Members of Congress to send collections to every portion of the country, and in the last year, on the request of individual Members of Congress, collections comprising in all at least 39,000 specimens were sent out. The National Museum is also treated as a National Bureau for scientific information, and is expected to answer inquiries from every portion of the country.

These are some of the purposes for which the Museum is compelled to use money which should go to collections, purposes not perhaps alien to the objects of a National Museum, but widely diverse from those of a private one.

The final result is shown in such figures as those above cited, where museums no larger or even of less extent, paying in many cases higher salaries to their officers and employees, are able to expend, as in the instance alluded to, thirteen times the amount on collections.

All these are reasons why, in spite of the most earnest efforts and self-sacrifice on the part of those in their immediate charge, the collections of the Government in many most important respects are not advancing as fast as those of some civic museums.

It seems but justice to the late eminent man—Dr. G. Brown Goode—who gave his life to this Museum, and who had entire freedom in his administration of it, to say that more than he did would have been, it is believed, impossible under the conditions just cited. He did more, in fact, than could be demanded, for he supplemented these defects by arousing, through his own enthusiasm and his unselfish interest, such a like spirit in others, that a large portion of all the curatorships are actually filled by those giving entirely voluntary and unpaid services, there being, in fact, more exactly, eight curators who are paid (though inadequately) to seventeen who receive their salaries in other Government employment, but give their private time to their respective departments, a condition of things which it would be hard to parallel elsewhere, but which alone has made it possible, under the depressing influences already cited, for the Museum to not have fallen further behind the progress of others than it has done. The clerical force, which is relatively larger than it would be under conditions other than

those stated, is paid at rates considerably less than for similar service in the Executive Departments.

I again most earnestly commend this most regrettable state of affairs to the attention of the Regents, and through them to Congress. It is for them to apply the remedy.

In my previous reports I have called attention to the congested state of the exhibition halls of the Museum, which prevents the collections from being seen to advantage. This condition has been met to a limited extent by the appropriation of $8,000 for galleries, which will afford a temporary relief; but it is evident that a new building must soon be provided, or the Museum will tend to present the appearance of a place for storage rather than that of one for commodious exhibition. There would not be the slighest difficulty in immediately filling a second building of the same size as the present one with objects of interest from the collections already accumulated.

It may possibly be a matter of surprise that I should urge the increase of appropriations for purchases, while the Museum building is thus crowded; but, as I have stated above, the present collections represent, in large part, not what is most desirable, but what has come to hand, leaving everywhere great gaps, or at least, fragmentary series which, to be properly presented, should be filled out by objects only obtainable by purchase.

BUREAU OF AMERICAN ETHNOLOGY.

The researches relating to the American Indians under the direction of the Smithsonian Institution have been continued. During the year special attention has been given to the more precise classification of the Indians by Maj. J. W. Powell, Director of the Bureau, and several of his collaborators; meantime the customary operations have been carried forward in such manner as to elucidate the arts, institutions, beliefs, and languages of the native tribes.

As usual a part of the work of the Bureau was exploratory. An extended exploration conducted by Mr. W J McGee, ethnologist in charge of the Bureau, was carried on over the territory of the Seri Indians, including Tiburon Island, in the Gulf of California, and adjacent mainland area in the State of Sonora, Mexico. These Indians are remarkable for primitive character and warlike disposition, and have successfully protected their habitat from invasion by white men since the time of Coronado. An account of this interesting journey will be found in Major Powell's report.

Archeologic explorations of considerable extent were carried forward also in Arizona, and some of the ruins thereby discovered were excavated with great success. The chief result of this work was a remarkably rich collection of symbolically decorated prehistoric pottery, made by Dr. J. Walter Fewkes and transferred to the United States National Museum.

Another noteworthy archeologic exploration was made along the western coast of Florida, south of the twenty-seventh parallel, bringing to light abundant relics of the prehistoric age. In this case the collections were taken chiefly from salt-water bogs within coral islands or atolls, in which domestic and ceremonial objects of wood, bone, shell, and antler, together with implements and weapons of shark and other teeth, and even textile fabrics were preserved in wonderful perfection. Water-color sketches were made of all masks and other wooden specimens liable to deteriorate in drying.

The work on the "Cyclopedia of the American Indians" has been carried forward, and a considerable part of the material has been made ready for the press.

Researches concerning the social organization and institutions of the Indians have been continued, and some of the results have been incorporated in the reports of the Bureau.

The work in linguistics has gone on steadily. A comparative vocabulary of Algonquian dialects is well advanced, and additions to it have been made through studies of the Miami and Peoria tongues. The tribal and linguistic development of the Iroquois Indians, or Six Nations, has been studied with success, yielding a means of determining, within limits, the prehistoric movements of these tribes. Substantial progress has been made also in ascertaining the general laws of linguistics and in applying these laws to the problems of the character and distribution of the aborigines.

One of the results of researches concerning the Kiowa ceremonials was the discovery that the Indians deepened their trance condition, and at the same time strengthened their bodies against fatigue, by the use of the dried tops of a cactus which contains certain alkaloids of remarkable properties.

The subject of native American mythology has received attention. It has been found that the myths and ceremonials throw much light on the origin and development of some of the industries and games of the Indians, and give an insight into many characteristics of primitive peoples in general. The ceremonials of the Pueblo Indians have been studied with care, and new indications have been found of the intimate connection between rituals and environment. A report dealing with the operations and ceremonials of the Zuñi Indians was practically completed during the year.

The Bureau made an exhibit in connection with the National Museum, under the Smithsonian Institution, at the Cotton States and International Exposition held at Atlanta during the autumn of 1896. This illustrated the characteristics and habits of the Cherokee Indians of eastern United States, of the Papago Indians of the far Southwest, and of the little known Seri of the western coast of Mexico. It received the highest award—a diploma and a gold medal.

The details of the Bureau's operations are recounted in a special report from Director Powell, forming Appendix II.

THE SMITHSONIAN INTERNATIONAL EXCHANGE SERVICE.

The International Exchange Service was inaugurated half a century ago as a means for developing and executing in part the broad and comprehensive objects paramount in the mind of the founder for the "increase and diffusion of knowledge."

The "increase of knowledge," accomplished only by constant research and persistent experiments, as prosecuted by the Institution in its various branches, would not alone have fulfilled the objects and attained the results desired by the founder. The knowledge obtained must also be diffused, and in order that the memoirs, contributions to knowledge, and annual reports published by the Institution might be systematically exchanged for publications of other scientific institutions throughout the world, the exchange system was inaugurated.

The advantages of the service have not been confined to the Institution alone, but have been shared by scientific societies and educational institutions everywhere for the ultimate purpose of increasing the resources of their libraries. That the best results might be attained, the Institution proceeded to establish relations with various scientific societies and libraries in England and Germany, where the interchange of publications was more extensive than in other countries, and it was found to be not only advisable but necessary that agents should be employed and paid some salary from the funds of the Institution. With the exception of the two countries named there is a systematic exchange of publications with nearly every nation of the civilized world without any expense to the Smithsonian Institution for the distribution of packages after the delivery of cases to the authorized agency.

Although the exchange service was originally established in the interest of science, for many years it has forwarded and received so many publications of the United States that the latter function has superseded the original design of the Bureau, both as to the number of packages and their weight, and especially since it became the official medium of the National Government for the distribution of parliamentary and scientific publications of the several Bureaus it has undergone a complete change and necessarily many improvements have been adopted in the system.

The appropriations made by Congress for the support of the exchanges since 1881 have never been adequate, notwithstanding the fact that treaty obligations made it compulsory for the Exchange Bureau to forward Government publications and receive the parliamentary documents of other countries for the Library of Congress. Without mentioning the cost to the Smithsonian Institution of the transmissions of the United States Government prior to the Exchange Bureau becoming the official representative of the Government, the Institution has advanced during that period over $45,000 from its own

income in excess of moneys appropriated by Congress, two-thirds of which at least was directly due to the expense of forwarding Government publications, and which has never been reimbursed to the Institution. The benefit derived by the Government from the exchange system has not been confined to the direct contributions of foreign governments, but the accumulations of the Smithsonian Institution have been systematically deposited with the Library of Congress, known as the "Smithsonian Deposit," and at the close of this fiscal year the publications thus deposited have reached the great number of 350,000.

By reference to the report, in the Appendix, of the acting curator of exchanges, it will be noticed that the expenditures of the year have amounted to $20,568.14. Of this amount $17,000 were appropriated by Congress, $2,727.43 were paid by Government bureaus, $271 by State institutions, and $461.29 by other contributors. This amount was insufficient to meet outstanding obligations, and the Institution advanced the sum of $98.42.

The number of correspondents of the Exchange Bureau, both foreign and domestic, has noticeably increased during the past year, and the total now amounts to 24,914, of which 18,900 are foreign, some of them being in the most remote parts of civilization.

I have before suggested the advisability of adopting some means by which to increase the store of parliamentary publications for the Library of Congress as a more adequate return for the large number of publications of this Government sent to foreign countries, and as the new Library building will in a few months be ready for cataloguing the books now on hand, and as ample space will be available for accessions, it seems most desirable that action should at once be taken to accomplish this end. Correspondence can do much, but personal solicitation can do more, and to attain the desired results a special representative in the joint interest of the Institution and the Library of Congress should be commissioned to visit the leading countries of the world.

THE NATIONAL ZOOLOGICAL PARK.

In former reports I have called attention to the general policy of the Institution with reference to the National Zoological Park and the embarrassments that have arisen in carrying it out. Some of these embarrassments still remain, especially the absence of authority for the purchase of animals in the appropriation act. Because of this the proper growth of the collection is much retarded and many of the rarer native animals now fast disappearing are not yet represented. It is not likely that such animals will often be presented to the park, as they are rarely obtained and are always readily sold. For several years past I have recommended to Congress the removal of this restriction by restoring to the annual appropriation act an item for the purchase of animals.

The appropriation made for the park for the fiscal year ending June 30, 1896, was in the following terms:

National Zoological Park: For continuing the construction of roads, walks, bridges, water supply, sewerage, and drainage; and for grading, planting, and otherwise improving the grounds; erecting and repairing buildings and inclosures for animals; and for administrative purposes, care, subsistence, and transportation of animals, including salaries or compensation of all necessary employees, and general incidental expenses not otherwise provided for, fifty-five thousand dollars, one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; for continuing the entrance into the Zoological Park from Woodley Lane, and opening driveway into Zoological Park, from said entrance along the west bank of Rock Creek, five thousand dollars, to be immediately available, which sum is hereby appropriated out of any money in the Treasury not otherwise appropriated, one-half chargeable to the revenues of the District of Columbia. And of the sum hereby appropriated five thousand dollars shall be used toward the construction of a road from the Holt Mansion entrance (on Adams Mill road) into the park to connect with the roads now in existence, including a bridge across Rock Creek.

The greater part of this sum has necessarily been spent in the maintenance of the collection and in the care of the buildings and grounds. It should not be forgotten that the preservation and maintenance of the native beauty of the region in which the park is situated was one of the primary objects had in view at the time of its establishment. In consequence of this, great care has always been exercised to interfere as little as possible with the natural features, though roads and walks following easy gradients and convenient for the public must necessarily be made through the park.

The adjustment of the boundaries of the park to conform to the newly devised system of highways that has been proposed for the District of Columbia has not yet been made. Since the date of the last report the roadways on the western side have received attention, and it is supposed that they are now definitely settled about the entire circuit of the park. It would seem, therefore, that the present is a proper time to make such final adjustments in the boundary as may seem desirable. The accompanying map shows the proposed roadways near the park.

The remarks made in last year's report with regard to changes upon the eastern side are still applicable in the main, and may be profitably repeated:

Plans for a system of roadways for the District have been completed for that section lying to the eastward of the park. Here a broad street, to be known as the "Park Drive," reaches the boundary of the park at its southeastern corner and thence proceeds along the eastern side by gentle curves adapted to the topography of the region, as shown upon the accompanying plan. The establishment of this road will greatly improve the access to the park, which has always suffered from the steep grades that are necessary for descent into the valley

of Rock Creek. It will, however, entail some new difficulties which should be met at once. The road does not skirt the boundary of the park at all points, but touches or leaves it according to the contour of the ground and the practicability of the grade. Some tracts of land are therefore left between the drive and the park, and if these become built upon, a succession of private houses will be thrust directly upon the boundary, marring the air of seclusion that was one of the objects for which the expenditure of the first purchase was made, and which is still a principal attraction of the valley.

In order to avoid this the land in question should be added to the park, the eastern boundary of which would then lie along a broad and excellent roadway affording access to the park at several convenient points. The accompanying map shows the land which should be added. It involves a strip (C) lying immediately south of the bear pits much needed for the security of the animals confined there. At present the boundary of the park is so near the pits that the bank is very steep, and as it is composed in considerable degree of soil and decomposed rock it constantly crumbles under the action of the weather and precipitates loose stones and débris into the pits, thus endangering the safety of the animals and gradually undermining the boundary fence, which must sooner or later fall inward. It should also include a tract of land lying on a hillside to the north of the Quarry road and forming a portion of the property of Mr. H. D. Walbridge. This is an exceedingly important tract, as its possession would extend the park toward Kenesaw avenue, which will doubtless be the principal route of access upon the eastern side, and it would be desirable to extend the park on the southern side by taking in the cemetery that now lies near the Adams Mill entrance and constitutes a serious blot upon the surroundings of the park.

In one particular it seems desirable to amend these recommendations. As the cemetery situated to the southward of the park is probably of considerable value and it would entail considerable expense to add the entire tract to the park, it is believed that the interests of the Government will be equally well subserved by establishing a roadway through it along the route marked in dotted lines on the map, and adding to the park only so much of the land as may lie between such roadway and the present boundary.

On the western side considerable readjustments of boundary are desirable. Commencing at Woodley Bridge, it seems proper that a small strip (marked H) should be added to the park, so that it may reach the line of a projected roadway shown in dotted lines on the annexed map. This roadway extends along the natural contours of a hill that slopes toward Rock Creek, and when it is established the unsightly embankment made there for the purpose of entering the park can be removed. It is recommended that the boundary run along the eastern side of this road to meet the present boundary of the park.

Another extension seems desirable near the present western entrance to the park upon Connecticut avenue extended. Here the boundary now runs at no great distance from the avenue and there is no properly legalized right of way over the property into the park. Notwithstanding this, the service of the electric cars on the avenue makes

National Zoological Park and Proposed Roadways in its Vicinity.

this the most frequented of all the entrances. The ground which it is proposed to include lies between the park and Connecticut avenue, extending southward to Cathedral avenue and northward to Klingle road. It is marked I on the accompanying map. It is represented as being excellent grazing ground for antelope, elk, deer, or llamas. Pasturage for these animals is now insufficient owing to the wooded character of the park. Should the Rock Creek Park be likewise extended to Connecticut avenue as is proposed, the two public parks would then have a common boundary along the Klingle road, which would form a common avenue of entrance.

It will be noted that there were mentioned in the appropriation act two roads to be constructed within the park, one entering from Woodley Lane road and continuing along the western bank of Rock Creek, a second to enter the park from the Adams Mill road and connect with the general park system.

The first of these roads is the one mentioned in last year's report. The amount of $5,000 appropriated for it, being immediately available, was nearly all expended before the beginning of the present fiscal year. Since this road has to be built within the boundaries of the park, it became necessary to make a heavy and expensive filling of earth near the Woodley road. This is at present a very objectionable feature that can not be modified except by an additional fill sufficient to modify the lines of the embankment so that they will simulate natural slopes. If the modification of the boundary and the exterior road proposed by the Commissioners is established here, this embankment should be removed or made to conform to the grades that accommodate such exterior road.

By consulting the annexed map it will be seen that this road soon reaches the banks of the creek. At this point it becomes necessary to cross, owing to the fact that the right or western bank becomes precipitous and would not admit of the construction of a road except at great expense and destruction of the natural features. It was first thought that it would be necessary to construct a bridge here, but this seems objectionable in some respects, as tending to give an artificial character to a beautiful locality. It is thought that it may be well to try at this point (marked A on map) the experiment of a ford, so managed that in ordinary stages of the stream there would be but a few inches of water. This would give sufficient access for carriages, and foot passengers could cross upon a series of stepping stones. There would be but few days in the year when such a crossing could not be used with satisfaction, and upon such days but little traveling would be expected.

The second road is in fact a restoration of the old road which led from the mill formerly established here by President John Quincy Adams, and accordingly known on the map of the District as the Adams Mill road. The mill with its dam has long since disappeared, but traces of the roadway and of the miller's dwelling still remain. It is believed that a picturesque driveway can be made here. It must necessarily be narrow, as otherwise it would deface too much the wooded bank

down which it descends. Work was commenced on this road toward the close of the fiscal year.

At the edge of the stream near the site of the old mill the two roads are to unite in one, which a short distance above will cross the creek on a rustic bridge (marked B on map), thus reaching the main body of the park near the principal animal house.

Among the most satisfactory of the works undertaken in the park for beautifying and secluding the grounds is the restoration of the area between the seal pond and Rock Creek to something approaching its primitive wildness. This region had been connected with the body of the park by high embankments meant to restrain the stream and prevent it from destroying the seal pond. This object has now been effected by removing the embankments and sinking under the ground at each end of the pond a substantial wall of masonry.

Through the courtesy of the Fish Commission the park was enabled during the year to acquire the plant for an aquarium which was used at the Atlanta Exposition. It is intended to establish this in a suitable structure, thereby effecting an important addition to the zoological resources of the park.

As the Yellowstone National Park is the source from which many wild animals are supplied to the park here, and as great difficulty has hitherto been experienced in properly confining and caring for animals within that preserve, it has seemed desirable that an inclosure of considerable extent should be fenced off in some suitable portion of that park into which animals could be driven for the purpose of capture and where they could be preserved indefinitely while becoming partially tamed and awaiting transportation to the East. A site for such an inclosure has been selected in the Hayden Valley, and during the summer of 1895 a strong corral inclosing a considerable tract was erected there. It was hoped that most of the few bison still remaining in the Yellowstone Park might be brought into this corral, and here protected from marauders. In this particular, however, my expectations have not been realized. The pursuit of the bison by poachers has continued, and it is understood from the superintendent of the park that there are now but very few remaining.

ASTROPHYSICAL OBSERVATORY.

The operations of the Astrophysical Observatory during the past year, as detailed more at length in the appendix, have been very successful in reducing prejudicial disturbances to the work. It is expected to make within a few months a publication of the results of the long investigation of the infra-red spectrum which has thus far occupied so much of the attention of the observatory. In this publication it is believed that the degree of accuracy in the position of absorption lines, which was mentioned in the report of last year as the aim of the investigation, will be fully realized.

Notwithstanding the gratifying progress in removing sources of error

which has been made during the past year, it must again be remarked that the full degree of satisfaction to be obtained in the investigation can not be hoped for in the present site of the observatory. During the past year plans have been prepared for the construction of a more suitable building, and some experiments have been made looking to the determination of a site more free from magnetic and other disturbances, but no steps have yet been taken to remove to such a situation.

It is proper to add that administrative duties have occupied too much of my time in the past year to permit my giving the personal attention I should have wished to the conduct of the observatory, and that for the improvements above described credit is due chiefly to Mr. C. G. Abbot, who efficiently aids me in its charge.

NECROLOGY.

GEORGE BROWN GOODE.

Since the close of the fiscal year the Institution has suffered the irreparable loss of its assistant secretary, Dr. George Brown Goode, who died on September 6, 1896, at his home in this city. A sketch of his life will more properly be given in my next report, but I can not refrain from saying a word at this time about one with whom I was not only officially intimate, but who was a very dear personal friend.

Dr. Goode was born at New Albany, Ind., on February 13, 1851. He was first associated with the Institution in 1873, and from that time until his death was thoroughly devoted to the work he so loved—the building up and development, under the charge of the Regents, of a great National Museum. In 1887 he was appointed assistant secretary of the Institution in charge of the National Museum, which, as it exists to-day, is perhaps the most fitting monument to his memory.

He possessed an exact scientific training that made him eminent as a zoologist, but it was as a specialist in museum administration that he was perhaps skilled above all others, and he gave himself with entire devotion to the care of the Museum, which was practically his charge, refusing many advantageous offers to go elsewhere, for the peculiar value of his services was everywhere acknowledged.

Dr. Goode united with his great administrative ability singularly varied powers in other directions, and the most entire unselfishness in their use I have ever known. My own trust in him grew with every evidence of his special fitness for it, while our official relations continued to be of the most happy character, and so also were those of his associates and subordinates, for he possessed the rare art of maintaining an exact discipline without sacrificing the affections of those over whom it was administered. He is gone, and his successor is hard to find.

WILLIAM CRAWFORD WINLOCK.

After the conclusion of the transactions of the Exchange Bureau for the fiscal year, and before the annual report of the Institution was

ready for the press, the curator of exchanges, William Crawford Winlock, passed away.

Mr. Winlock died at Bay Head, N. J., September 20, 1896, having but a few days before returned from a journey to London, Leipsic, and Paris, whence he had gone in the interest of the affairs of the Bureau.

Mr. Winlock, already well known as an astronomer, having been attached to the United States Naval Observatory, continued to exercise the functions of his profession after associating himself with the Institution, and, in addition to his onerous duties as curator of exchanges, he was made honorary curator of physical apparatus in the United States National Museum. At the time of his death he occupied the chairs of astronomy in the Corcoran and Graduate schools of the Columbian University.

In the death of Mr. Winlock the Institution has lost not only one of its most efficient officers, and one to whom the exchange service was specially indebted, but one whose personal character endeared him in an uncommon degree to his associates.

GEORGE HANS BOEHMER.

George Hans Boehmer died at Gaithersburg, Md., November 20, 1895. Mr. Boehmer was born in Berlin, Germany, May 6, 1842, and in 1868 came to the United States.

In 1876 he was appointed on the staff of the Smithsonian Institution, and after various promotions became chief clerk of the Exchange Bureau, which position he held at the time of his death. He was an accomplished linguist, and his efforts aided greatly in bringing the Exchange Bureau to its present efficient standing.

Respectfully submitted.

S. P. LANGLEY,
Secretary of the Smithsonian Institution.

APPENDIX TO SECRETARY'S REPORT.

APPENDIX I.

THE NATIONAL MUSEUM.

SIR: The following statement constitutes a résumé of the most important operations of the National Museum during the fiscal year which ended on June 30, 1896:

Accessions.—The records show the receipt of 1,299 separate accessions during the year. These represent a total of more than 70,000 specimens of all kinds.

The following accessions are of special interest: From Dr. William L. Abbott, to whom more than any other individual the Museum is indebted for contributions from Africa and Asia, collections of natural-history specimens, ethnological objects, and musical instruments, gathered in Kashmir, India, and Madagascar; from Mr. A. Boucard, Isle of Wight, England, large and exceedingly valuable collections of birds' skins from different parts of the world, containing many species and several genera new to the Museum collection; from Dr. L. T. Chamberlain, New York City, a valuable collection of southern gems and gem minerals, native silver from Arizona, an especially fine specimen of green tourmaline from Mount Mica, Paris, Me., and shells from New Zealand and various localities in Texas; from John Brenton Copp, New Haven, Conn., a very interesting addition to the collection of household goods, wearing apparel, pottery, glass, pewter jewelry, and other specimens transmitted by him in a previous year; from Dr. A. Fenyés, Hélouan, Egypt, a fine collection of natural-history specimens, fossils, Greek and Roman coins, and antiquities from Egypt and the Transvaal; from Mr. R. D. Lacoe, Pittston, Pa., collections of Dakota group fossils and Paleozoic animal fossils, also specimens from a Sigillarian stump. These collections will form part of the famous "Lacoe Collection." Col. Charles Coote Grant, Hamilton, Ontario, Canada, has transmitted a large collection of Clinton and Niagara group fossils from the vicinity of Hamilton. Dr. William L. Ralph, Utica, N. Y., to whom the Museum is so deeply indebted, has presented some very valuable and interesting collections of birds' skins. Among them is a skin of a Philip Island parrot, now an extinct species. Lieut. Wirt Robinson, U. S. A., Hubbard Park, Cambridge, Mass., transmitted collections of birds' eggs from Virginia, birds' skins, including several new species, from Margarita Island and Venezuela, as well as some natural-history specimens from the West Indies. Some very beautiful specimens of the Tiffany Favrile glass, made under the personal supervision of Mr. Charles L. Tiffany, have been deposited in the Museum by Messrs. Tiffany & Co. Special mention may also be made of a number of pieces of beautifully decorated chinaware, pottery, etc., presented by Messrs. William and Edward Lycett, Atlanta, Ga., including vases, cups, and saucers of Japanese eggshell porcelain.

The scientific staff.—The vacancy created by the death of Prof. C. V. Riley, honorary curator, on September 14, 1895, has been filled by the appointment of Mr. L. O. Howard, who also succeeded Professor Riley as Entomologist of the Department of Agriculture. Custodians of special groups in the Department of Insects have been appointed, as follows: Mr. D. W. Coquillett, custodian of the Diptera; Mr. W. H. Ashmead, custodian of the Hymenoptera; Mr. E. A. Schwarz, custodian of Coleopterous larvæ, and Mr. O. F. Cook, of Huntington, Long Island, custodian of the Myriapoda.

Mr. George C. Maynard has accepted the custodianship of the collection of electrical apparatus. Dr. C. Hart Merriam has been enrolled upon the list of associates in zoology.

Distribution of specimens.—Nearly 30,000 specimens of all kinds have been distributed during the year. About four-fifths of this number were donated to institutions. The total also includes a large number of specimens which were transmitted in exchange to institutions and individuals. Specimens are in no case given to individuals. Of the entire number of specimens distributed, probably two-thirds consisted of fishes and invertebrate forms of marine life. More than 2,300 geological specimens and about half as many casts of prehistoric implements are also included in the total number.

Visitors.—The number of visitors to the Smithsonian building during the year was 103,650, and to the Museum building 180,505.

Specimens received for determination.—There has been a noticeable increase in the number of "lots" of material received for identification. This is readily accounted for by the encouragement which the Museum has always given in this direction. A stone or insect, actually worthless, but believed by the sender to have some scientific or commercial value, is as carefully examined and reported upon as would be a collection having recognized value, from a correspondent known to be engaged in scientific work. The number of "lots" received during the year was 542, or an increase of 75 over the number received last year.

Foreign exchanges.—Exchanges have been made with a number of foreign museums. Among them may be mentioned the Royal Zoological Museum, Florence, Italy; Museu Paulista, Sao Paulo, Brazil; British Museum, London, England; Zoological Museum, Turin, Italy; Horniman Museum, London, England; Australian Museum, Sydney, New South Wales; La Plata Museum, La Plata, Argentina; Museum of Natural History, Paris, France; Museum of Natural History, Genoa, Italy; Royal Zoological Museum, Copenhagen, Denmark; Imperial Zoological Museum, Vienna, Austria. Exchanges of importance have also been made with individuals, among whom may be mentioned Mr. Edward Lovett, Croydon, England; Mr. Edgar J. Bradley, Happy Valley Water Works, South Australia; Dr. A. C. Haddon, Cambridge, England; Prof. Guiseppe Bellucci, Perugia, Italy; Dr. Herman Credner, Leipsic, Germany; Dr. A. Pavlow, Moscow, Russia; Col. Charles Scott Grant, Hamilton, Ontario, Canada; Prof. M. Stossich, Trieste, Austria.

Publications.—The Report of the National Museum for 1893 was published early in the year, and a considerable portion of the Report for 1894 is already in type.

Volume 17 of Proceedings of the National Museum was received from the Government Printing Office and distributed in July. All the papers for Volume 18, excepting three, appeared as separates. This volume will probably be ready for distribution in bound form during November. Advance editions of three papers to appear in volume 18 were also received and distributed. Two of these contained descriptions of remarkable new genera and species of batrachia and crustacea obtained by the United States Fish Commission from an artesian well at San Marcos, Tex. The third contained preliminary diagnoses of new mammals from the Mexican border, collected by Dr. E. A. Mearns, U. S. A.

Bulletin 47, "The Fishes of North and Middle America," by Dr. D. S. Jordan and Prof. B. W. Evermann, will shortly be published, and Bulletin 49, "A Bibliography of the Published Writings of Philip Lutley Sclater, F. R. S." prepared by Dr. G. Brown Goode, is now in type.

A second edition of Part F of Bulletin 39, "Directions for Collecting and Preserving Insects," by Prof. C. V. Riley, has been printed, to meet the unusually large demand for this pamphlet.

Special Bulletin No. 2, "Oceanic Ichthyology," by Dr. G. Brown Goode and Dr. Tarleton H. Bean, is now ready for the press. This is a treatise on the deep-sea and pelagic fishes of the world, and is based chiefly on the collections made by the steamers *Blake*, *Albatross* and *Fish Hawk* in the Northwestern Atlantic Ocean. It is an elaborate work, in quarto form, of 553 pages, with an atlas of 417 figures arranged on

123 plates. Special Bulletin No. 3 is also ready for the press. This is the second volume of "Life Histories of North American Birds," by Maj. Charles Bendire.

In the series of circulars, No. 47 has been issued. The object of the circular is to indicate the conditions upon which the Museum will undertake the identification of mollusks. The necessity of printing such a circular arose from the vast amount of material of this kind received for examination during recent years. In almost every instance the return of the material was expected, and thus the Museum was called upon to do a very large amount of work with little or no return of any kind.

Explorations.—Dr. William L. Abbott has continued his explorations in Africa and India, and the Museum is deeply indebted to him for additional collections of ethnological and natural-history objects. Among the latter, a fine series of skins of lemurs and of the insectivores peculiar to southeastern Madagascar are of conspicuous interest and value.

A valuable collection, consisting of 1,553 specimens of antiquities, obtained in 1895 from the cliff dwellings and ancient pueblos near Tusayan, Ariz., has been gathered by Dr. J. Walter Fewkes. This collection will doubtless be supplemented by others of equal interest, as Dr. Fewkes is continuing his explorations this summer (1896).

A very acceptable collection of natural-history material was obtained for the Museum by Lieut. Wirt Robinson, U. S. A., during his travels in the West Indies and South America.

Additional collections of mammals, birds, and other natural-history specimens, obtained in Virginia, Pennsylvania, and the Gulf of California, have been received from Dr. Edgar A. Mearns, U. S. A.

A collection of objects illustrating the manner of life among the Kiowa tribes has been gathered by Mr. James Mooney, of the Bureau of Ethnology, and transferred to the National Museum.

As a result of explorations in a cavern near Duffield, Scott County, Va., conducted by Gen. A. L. Pridemore, of Jonesville, Va., the Museum has received a large collection of human bones.

Important collections have been received from the United States Fish Commission, comprising material collected in various parts of the United States by exploring parties sent out under the direction of the Commission. The Department of Agriculture has been instrumental in adding, through its explorations, to the Museum collections. A fine collection of Lower Silurian fossils from Valcour Island, Lake Champlain, and of trilobites from Rome, N. Y., was made by the United States Geological Survey, and will in due course be transmitted to the Museum. Several large and valuable collections have been received from this source during the year.

Prof. R. Ellsworth Call, of Cincinnati, Ohio, has explored some of the caves in Kentucky, and has transmitted to the Museum a large number of bats from the Mammoth Cave.

Several of the curators and assistant curators in the Museum have at various times during the year been engaged in collecting material. The results of these expeditions, which were for the most part very successful, have been incorporated into the Museum collections.

Cotton States and International Exposition, Atlanta.—The exposition opened on September 18 and closed on December 31. Fourteen departments of the Museum were represented by special exhibits, and also several sections of the department of arts and industries. The sum allotted to the Institution and the Museum was $22,000. The Museum report for this year (1895–96), now in course of preparation, will contain an elaborate report upon the exhibits of the Institution and the Museum, accompanied by detailed lists of the objects exhibited.

Respectfully submitted.

G. Brown Goode,
Assistant Secretary in Charge of the U. S. National Museum.

Mr. S. P. Langley,
Secretary of the Smithsonian Institution.

August 1, 1896.

APPENDIX II.

REPORT OF THE DIRECTOR OF THE BUREAU OF AMERICAN ETHNOLOGY FOR THE YEAR ENDING JUNE 30, 1896.

SIR: Ethnologic researches have been carried forward throughout the fiscal year in accordance with the act of Congress making provision "for continuing researches relating to the American Indians, under the direction of the Smithsonian Institution."

As heretofore, the operations have been conducted in accordance with a plan submitted at the beginning of the fiscal year. Field operations of considerable extent have been carried on in Arizona, Florida, Indian Territory, Indiana, Maine, New Mexico, Oklahoma, and Sonora, Mexico. The office researches have been carried forward by the use of material from most of the States and from various other parts of the continent.

CLASSIFICATION OF THE WORK.

The immediate purpose of the Congress in instituting the Ethnological Bureau was to obtain definite information concerning Indian tribes, to the end that they might be arranged in amicable groups on reservations; and this primary purpose has been constantly borne in mind and has from the beginning shaped the operations of the Bureau. In considering the qualities which conduce toward amity or tend toward enmity among the tribes it was found that differences in mythology or belief commonly engender distrust and strife, while similarities in mythology inspire mutual confidence and thus promote peace; accordingly, it was deemed necessary to investigate the aboriginal mythology. It was also found that tribes and confederacies controlled by similar laws and governed by chiefs chosen in the same way, and organized or regimented on parallel lines, usually associate peacefully, while tribes or other groups whose institutions are unlike can not associate without friction and clashing; thus it seemed desirable to take up researches concerning the institutions of the aborigines, and the early work in this direction proved so fruitful as to encourage its prosecution. It was found, too, that tribes and other groups whose industrial arts, sports, and games are of allied character are commonly harmonious, while Indians whose arts are diverse are suspicious of each other and prone to animosity; and for this and other reasons it was deemed needful to investigate the aboriginal arts.

Finally, it was found that there is a relation between the beliefs, institutions, and arts of the Indians and the languages spoken by them, and as the researches progressed this relation was found so intimate that the languages may safely be regarded as indexes to those qualities, and hence that language alone can safely be used as a basis for the determination of tribal qualities and for the arrangement of the Indians in amicable groups. Accordingly, much attention was given to linguistic researches, and gradually most of the tribes of the United States, with some of those in the contiguous territory, were classified on a linguistic basis. Meanwhile investigations concerning other subjects were carried forward, and were found of much importance. In this way four primary lines of research were developed. So far as practicable, the operations of the Bureau have been so conducted as to advance knowledge equally along the several lines. Practical considerations have, however, led to a somewhat arbitrary division of the work into the commonly recognized departments (1) archeology, (2) descriptive ethnology, (3) sociology, (4) linguistics, (5) mythology,

(6) psychology, (7) bibliography, and (8) publication, with the necessary administrative and miscellaneous work. Most of the researches are necessarily carried forward in the field, while the field material is elaborated in the office. Accordingly, the field work and the office work are treated together except in so far as the former may be considered exploratory, when it commonly relates to different lines of primary research.

EXPLORATION.

At the beginning of the fiscal year Dr. J. Walter Fewkes was in the field in Arizona, having completed during June a reconnoissance of the little-known country including the northeastern extension of the Mogollon escarpment about the head waters of Rio Verde. He repaired early in July to Holbrook, and proceeded to explore the ruined villages of northeastern Arizona. After a more or less successful reconnoissance extending over a considerable district, he chose for detailed work the ruin known as Sikyatki. Here he was joined by Mr. F. W. Hodge. It was ascertained through tradition and literary record that the ruin represented a wholly prehistoric village; and excavations were begun with the certainty that all material exhumed would, for this reason, be of especial value in indicating the aboriginal condition of the pueblo builders of this district. The anticipations were fully realized in the results. In all of the abundant material exhumed and duly transferred to the United States National Museum no trace of intrusive accultural art was found; every piece was clearly prehistoric; and the collection was the richest both in quantity of material and the quality of the ware and its symbolic decoration thus far obtained in this country. While it is especially rich in decorated pottery, many other articles illustrating primitive handicraft and customs were obtained, together with a sufficient amount of somatologic material—crania, etc.—to reveal the prominent physical characteristics of the ancient people. Extensive collections were made also in the ancient ruin of Awatobi. Dr. Fewkes' operations were brought to a close toward the end of August, when he returned to Washington with his collections, comprising seventeen boxes from Sikyatki and Awatobi, and three from the ruins on the head waters of Rio Verde.

Separating from Dr. Fewkes at Holbrook about the end of August, Mr. Hodge made a reconnoissance of all the inhabited pueblos of New Mexico comprising Zuñi, Acoma, and Laguna in the western part of the territory, Cochiti, San Felipe, Santo Domingo, Santa Ana, Sia, Jemez, Isleta, Sandia, Taos, Picuris, Santa Clara, San Juan, San Ildefonso, Pojoaque, Nambe, and Tesuque, in the valley of Rio Grande. At nearly all of these pueblos he was able to obtain valuable information relating to the social organization, beliefs, migrations, and affinities of the natives. In several cases the Indians have remained so completely isolated as to be little known to students, and accordingly much of the information is essentially new.

The early part of the year was spent by Mr. James Mooney in the field in Oklahoma in researches concerning the Kiowa Indians, the details of which are set forth elsewhere.

Noteworthy exploratory work was conducted by Mr. W J McGee in continuation and extension of the explorations in Arizona and Sonora, Mexico, begun during the last fiscal year. Outfitting at Tucson, Ariz., he started southward on November 9, 1895, crossing the frontier at Sasabé and proceeding thence in a different direction from that already reconnoitered. By the middle of the month he reached the most elaborate prehistoric works existing in northwestern Mexico, near the rancho of San Rafael de Alamito, on the principal wash known locally as Rio Altar. The works comprise terraces, stone walls, and enclosed fortifications, built of loose stones, nearly surrounding two buttes, of which the larger is three-fourths of a mile in length and about 600 feet in height.

These ruins are known locally as "Las Trincheras," or as "Trinchera" and "Trincherita." The whole of the northern side of the larger butte is so terraced and walled as to leave hardly a square yard of the surface in the natural condition;

and for hundreds of square rods the ground is literally sprinkled with fragments of pottery, spalls, and wasters produced in making chipped implements, and other artificial material. Mr. Willard D. Johnson, who accompanied the party as topographer (on furlough from the United States Geological Survey), and who carried forward a route map, made detailed surveys of these ruins; a number of photographs were taken also, while a considerable collection representing the fragmentary pottery and stone art of the builders was obtained. After some days spent at this locality the expeditions pushed on southward, traversing the principal mountain range of western Sonora in a narrow canyon below Poso Noriega, and thence following for 50 miles the sand wash known as Rio Bacuache, which was not previously mapped. Leaving this wash near its indefinite termination on the desert plains, the course was headed toward Rancho de San Francisco de Costa Rica, where a rancheria of Seri Indians was found in 1894. On reaching this point it was ascertained that the Indians had, through a combination of circumstances, become more hostile toward white men than ever before, so that the prospect for studying their arts, institutions, and beliefs seemed most gloomy. Nevertheless, it was decided to make the effort.

At the rancho a rude boat was built, with the aid of Señor Pascual Encinas, of Hermosillo; a preliminary trip was then made over the continental portion of Seriland, including the Seri Mountains, which were ascended for the first time by white men, and were carefully mapped by Mr. Johnson. It was expected that the Indians would be encountered on this trip; but unfortunately there had been a skirmish between a small party of the Seri and a party of Mexican vaqueros two days before the expedition entered Seriland proper, and the Indians had apparently withdrawn to the coast and Tiburon Island. Returning from this side trip, the boat was, with much difficulty, transported across Encinas desert and launched in Kino Bay, a reentrant in the coast of the Gulf of California. The stock, with the teamsters and guides, were sent back to the rancho, while the main party proceeded up the coast to the strait separating Tiburon Island from the mainland. It had been estimated from the best available data that from five to seven days would be required for crossing the strait, surveying Tiburon Island, and making collections; and ten days' rations with five days' water supply were provided. The party, in addition to the leader, comprised Messrs. W. D. Johnson, topographer, J. W. Mitchell, photographer, and S. C. Millard, interpreter; Señores Andres Noriega, of Costa Rica, and Ygnacio Lozania, of Hermosillo; Mariana, Anton, Miguel, Anton Castillo, and Anton Ortiz, Papago Indians; and Ruperto Alvarez, a mixed-blood Yaki. A military organization was adopted, strict regulations were laid down for the protection of life and property, and watches were instituted and rigidly maintained.

On proceeding up the coast toward the turbulent strait El Infiernillo, severe gales were encountered, whereby progress was greatly retarded; and on reaching the strait the winds continued to blow so violently as to fill the air with sand ashore and spray at sea, and to render it impossible to make the passage. Finally, after five days, when the water was exhausted, the gale lulled sufficiently to permit a difficult crossing with a portion of the party and a small part of the scanty food and bedding; but when Messrs. Johnson and Mitchell set out on the return trip to bring over Señor Noriega and two of the Indians, who remained with the supplies on the mainland, the gale rose again and, despite the most strenuous efforts, blew the frail vessel 25 miles down the gulf, where it was practically wrecked on a desert island. On the following day the wind subsided somewhat, and the two men were able to empty the boat of the sand with which it had become filled, to repair it, and finally to reach the rendezvous on the shore of Kino Bay in time to meet the teamsters from the rancho on their return to bring in the party. Here water was obtained, and Messrs. Johnson and Mitchell again worked their way up the coast in the face of adverse winds, usually tracking the boat laboriously along the rocky coast; but it was not until the end of the fourth day that they rejoined the three men left on the mainland, who had suffered much from thirst, and again crossed the strait to find the larger portion of the party with the leader on Tiburon Island. Meantime the group on the

island had suffered inconvenience from dearth of food and blankets, and had been compelled to devote nearly all their energies to obtaining water from a little tinaja, or water pocket, in the rocks in the interior of the island 6 or 7 miles from the shore. All hope of return of the boat had been abandoned, and when it finally appeared the party were collecting driftwood and branches of the palo blanco—a tree growing sparsely on the mountains in the interior of the island—to build a raft, while one of the party was engaged in making the necessary ropes from provision-bags and clothing.

On the reassembling of the party the original plans were resumed; the leader visited a score or more of Seri house bowers or rancherias, only to find them abandoned (though some bore evidence of occupancy within a few hours) while Mr. Johnson continued the topographic surveys. By this time the food supplies were practically exhausted, but were eked out by collecting oysters, clams, and crabs and by a shark taken on the next to the last day of the stay on the island; and, as before, most of the energies of the party were expended in carrying water from 4 to 15 miles, for which purpose squads of five or more heavily armed men were requisite, since the danger of ambush was considerable and constant. By these journeys over the jagged rocks, in which Tiburon Island abounds, the shoes of the white men and the sandals of the Indians were worn out; and this condition finally compelled the abandonment of further effort to come into communication with the wary Indians. Considerable collections representing their crude arts, domestic and maritime, were, however, made in their freshly abandoned rancherias, and a fine balsa, or canoe-raft made of canes, was obtained.

After some delay and danger the strait was recrossed, and the party found themselves on the mainland, still beset by storms, without food or water, reduced by arduous labor and insufficient food, and practically barefoot in a region abounding in thorns and spines and jagged rocks. Moreover, they were still constantly under the eyes of Seri warriors watching from a distance and awaiting opportunity for attack. After fully considering the situation, the leader left the party and the boat in charge of Mr. Johnson and skirted the coast on foot for 25 miles to the rendezvous on Kino Bay in the hope of reaching the teamster from the rancho with supplies on the last day of his stay there under the instructions given him by Mr. Johnson, on last leaving that point after the wreck. He reached the rendezvous early in the night of December 28, only to find it abandoned by reason of the accidental escape of the stock. He at once pushed on across the desert to the rancho, reaching there early in the morning of the 29th, and immediately returning with food and water. The entire party arrived at the rancho on the evening of December 31, and two days later proceeded to Hermosillo, whence the leader returned directly to Washington, while Mr. Johnson retraversed the country, thence northward to the Arizona boundary, collecting objects and information among the Papago Indians and completing the triangulation and topographic surveys. He reached Tucson about the end of January.

While the expedition was, by reason of the hostility of the Indians, unsuccessful so far as the anticipated studies of the Seri institutions and beliefs are concerned, considerable collections representing their arts were obtained. Moreover, the whole of Seriland, the interior of which was never before trodden by white men, was examined, surveyed, and mapped; and the expedition resulted also in a survey of such character as to yield the first topographic map of a broad belt in Sonora extending from the international boundary to Sonora River. The area covered by this survey is about 10,000 square miles. Forty-seven stations were occupied for control, and a considerably larger number of additional points for topographic sketching. The portion of the map comprising Seriland, being essentially new to geographers, has been published in the National Geographic Magazine (Vol. VII, 1896, Pl. XIV). It is a pleasure to say that the work of the expedition was facilitated in all possible ways by the State officers of Sonora and the federal authorities of the Republic of Mexico. By special authority of His Excellency Señor Leal, secretario de fomento,

the party was permitted to cross the boundary with the outfit and necessary supplies; while the governor of Sonora, Señor Ramon Coral, offered to furnish a guard of state troops, and in other ways displayed constant interest in the work of the expedition. Much is due, also, to Señor Pascual Encinas, an intrepid pioneer, to whose courage and energy the extension of settlement in the borders of Seriland must be ascribed, and a well-known citizen of Hermosillo, without whose assistance the work would have been crippled.

Office Work.

ARCHEOLOGY.

Dr. J. W. Fewkes brought his field explorations and excavations to a close toward the end of August and proceeded to Washington, where he was for several months employed in unpacking, cleaning, repairing, labeling, and installing in the National Museum the collections of pottery and other aboriginal material obtained in the course of his work in Arizona. In connection with this duty he prepared a general paper on the results of his work for the annual report of the Smithsonian Institution, and began the preparation of a more extended and fully illustrated memoir for incorporation in the seventeenth annual report of the Bureau; he was occupied on this memoir during most of December, 1895, and until his departure to the field in May, 1896. In this report especial attention is given to the symbolic decoration of the pottery and to its bearing on the mythology of the Pueblo Indians.

Toward the end of the fiscal year Dr. Fewkes returned to the field for the purpose of making excavations and surveys of ruins brought to light through his previous reconnoissance. He was accompanied by Mr. Walter Hough, of the National Museum, who was detailed as a field assistant for the season. The operations were commenced at the ruin known as Homolobi, on Little Colorado River, about 3 miles from Winslow, Ariz. As indicated by tradition, this village was the ancient home of a Moki Indian clan. For a time the results of the work were not encouraging, but toward the middle of June a productive part of the ruin was reached, and within a few days 400 fine specimens were obtained, including 250 beautiful bowls, dippers, vases, jars, and other specimens of aboriginal fictile ware, similar to that obtained from Sikyatki during the preceding season. Examination showed that the ware is typically Tusayan, yet in its form and decoration is archaic and without influence of civilized culture, thus demonstrating prehistoric character. The work at this point continued successful until the ruin was exhausted. The party then repaired to another site, known as Chevlon Pass, on Little Colorado River, also discovered by Dr. Fewkes. There the excavations were successful almost from the first, so that by the end of June the field catalogue of specimens had passed the number of 1,000. Several unique and especially significant objects were brought to light at this ruin. Some of the pottery found here is remarkably fine in texture, form, and decoration. Numerous baskets were also recovered, as well as cotton cloth, sandals, pahos (or ceremonial wands), and marine shells. Although Dr. Fewkes' collections during the summer of 1895 were unprecedented in wealth and scientific value, for the United States, his collections during the first half of the season of 1896 were even richer and more significant in their bearing on ethnic problems.

Early in December, Mr. Frank Hamilton Cushing proceeded to Florida to resume the researches relating to the Seminole Indians and to the archeology of that region, which were commenced several months before and temporarily discontinued by reason of the inadequacy of the funds at disposal for field work. It was found impracticable to make the requisite allotment for necessary field expenses, and a tender was accepted from the Archeological Association of Philadelphia, representing the Museum of the University of Pennsylvania, for cooperation. Under the terms of the cooperation the Archeological Association assumed the cost of field work, including the subsistence of the party, the salaries of assistants to Mr. Cushing, and incidental expenses connected with the operations, while the material proceeds, in the

form of collections, became the joint property of the Bureau and the association, to be divided after examination and use in the preparation of reports, and the scientific results remain the property of the Bureau for publication. Under this arrangement Mr. Cushing organized a party, including Mr. Wells M. Sawyer, of the United States Geological Survey (furloughed for the purpose), as photographer and artist; Mr. Carl F. W. Bergmann, formerly of the United States National Museum, as an expert assistant in collecting; Mr. Irving Sayford as clerk; and a number of workmen, who were engaged in excavation. Several localities were reconnoitered and exploited with moderate success. During February the work was pushed into the region of coral islands in the neighborhood of Punta Rassa, where traces of extensive aboriginal handiwork were found on the islands, and especially in ancient atolls and lagoons lined with bogs and saline marl. Here the works were of such character as to indicate an extensive and well-organized primitive population, subsisting on sea food, and cruising not only the lagoons and bays but also the open gulf. Their island domiciles were protected by dikes built of large sea shells, evidently collected for the purpose; their habitations, at least in part, were pile structures, ruins of which still remain. In some cases these structures were occupied so long that the kitchen refuse accumulated to form mounds (initiating in time the custom of erecting mounds as sites for domiciles), and within the refuse heaps, or midden-mounds, extensive traces of handiwork of the people were found.

The most extensive collections were, however, made from the bogs adjacent to the habitations or beneath habitations occupied too briefly to permit extensive accumulations of middens. In these bogs were preserved numerous artifacts, comprising shellwork in large variety; wooden ware, including utensils, tools, weapons, masks and other ceremonial objects, often elaborately carved and painted; textile fabrics and basketry in abundance, though usually in such a state of decay as hardly to be preservable; implements and other objects partly or wholly of teeth and bone of sharks, land animals, etc.; and a few stone implements of the usual aboriginal character. The painting and carving are especially noteworthy, not only as indicating moderately advanced symbolic art of the native type, but as suggesting community of culture between the maritime people of Florida and prehistoric peoples of the western and southern shores of the Gulf of Mexico. The handiwork shows no trace of accultural influence, and must therefore be regarded as pre-Columbian, though the mode of life indicated by the relics is similar to that observed on the Floridian peninsula by the earliest white explorers. The wooden ware, textiles, etc., preserved in the salt-water bogs commonly retained their aboriginal appearance until exposed to the air, when they rapidly disintegrated and fell to pieces, or else shrunk or warped so greatly as to give little indication of the original form. A considerable part of the energies of the party were expended in efforts to preserve these perishable articles by various devices and the use of such materials as could be obtained at points remote from civilized stores, while Mr. Sawyer was constantly employed in photographing or in drawing and painting in the original colors all the more perishable objects; in this way the evidence concerning the prehistoric people recorded in the better-preserved portions of the collection was greatly amplified and extended.

In April the Director visited Mr. Cushing and remained with the party, personally inspecting and directing the work, for several days. The operations in Florida were brought to a close in May, when the collections were carefully loaded in a car and transported direct to Philadelphia, where the space and facilities for unpacking were ample. Mr. Cushing returned to Washington, and on the arrival of the car proceeded to Philadelphia, where he unpacked that portion of the collection required for immediate study.

Mr. Cushing's Florida work threw new light on the shell mounds and other aboriginal works on the American coasts, and it was accordingly thought desirable to review the earlier and more superficial examination of these works at different points along the coast. Carrying out this plan, the Director proceeded about the middle

of June to the coast of Maine, which has long been known to abound in aboriginal shell heaps; there he was soon afterward joined by Mr. Cushing, and surveys and examinations of the prehistoric works were under way at the close of the fiscal year.

DESCRIPTIVE ETHNOLOGY.

As administrative duties permitted, Mr. F. W. Hodge (acting chief clerk) carried forward the Cyclopedia of the American Indians, his field work among the pueblos in August and September yielding much information concerning the relations, and especially concerning the clan organization of the southwestern Indians. In February Dr. Cyrus Thomas, having completed his revision and extension of work on Indian land treaties, was transferred to the Cyclopedia, and during the remainder of the fiscal year he was employed in collecting and arranging material relating to the tribes of the Algonquian stock. The character of this Cyclopedia was set forth fully in the last report.

During the earlier part of the year Dr. Thomas revised and brought up to date the Royce memoir on treaties with the Indian tribes relating to the cession of lands (also described in the last report). The task proved greater than anticipated, since extended research was required for bringing the work to date, and since this necessitated the reconstruction of several of the maps. The laborious work was carried forward energetically by Dr. Thomas, and the requisite additions to and modifications in the schedule were made, the maps were prepared, and an introductory and explanatory chapter was written. The work was completed early in April, and was prepared for transmission to the Public Printer for issue as Volume VIII of the Contributions to North American Ethnology, when on examination of the statutes it was found that the public printing law approved January 12, 1895, seems to terminate that series; accordingly, the document was held for incorporation in a forthcoming annual report.

In the early part of the year Mr. James Mooney was employed in the field in researches among the Kiowa and Comanche Indians of Oklahoma and Indian Territory. One of his lines of research related to the camping circle of the Kiowa-Comanche group, in which the tents are arranged in a certain definite order expressing the social organization and conveying other symbolic meanings; his studies extended also to the patriarchial shields attached to the tents, and to the drawings and paintings by which both shields and tents are decorated. He has found that all of these decorations are symbolic, and collectively represent a highly elaborate system of heraldry, and most of his time in the field was devoted to tracing the ramifications and interpreting the details of the heraldic system. Special attention, too, was given to the calendars, or "winter counts," of which several were found among these Indians. These calendars, which represent the beginning of writing, are long-continued records of current events, represented pictographically by rude drawings and paintings on skins or fabrics; and from them the important events in the history of the tribes for many years can be determined with accuracy.

Another line of research related to the use of "mescal" by several of the southern plains' tribes in their ceremonials as a paratriptic and mild intoxicant; this article, as used by the Indians, is the upper part of the cactus known botanically as *Anhalonium lewinii, or Lophophora williamsii lewinii*, which grows in the arid region of Texas and eastern Mexico. The tops of the plants are collected and dried, when they form button like masses an inch or more in diameter and perhaps one-eighth of an inch in thickness; these buttons are eaten by the Indians in certain protracted and exhausting ceremonials. Their effect is to stimulate and invigorate the system to such an extent as to permit active participation in the dance and drama for many consecutive hours without fatigue, while at the same time mental effects somewhat akin to those of hashish are produced, whereby the condition of trance or hallucination, which plays so important a part in all primitive ceremonials, is made more complete than is customary or even possible under normal circumstances. In addition to the study of effects produced on the Indians themselves by the use of the

poison, Mr. Mooney collected a considerable quantity of the material for scientific examination. By courtesy of the Department of Agriculture, the buttons were analyzed by Dr. Harvey W. Wiley and Mr. E. E. Ewell, of that Department, and were found to yield three alkaloids, designated, respectively, as anhalonine, mescaline, and alkaloid 3, besides certain resinous substances, all possessing peculiar physiological properties. The physiologic action of the mescal buttons administered entire, and also of the three alkaloids, has been tested by D. W. Prentiss, M. D., and F. P. Morgan, M. D., and the results have been found of great interest, leading the experimentalists to consider the extracts as important therapeutic agents and valuable additions to the pharmacopœia. On his return from the field Mr. Mooney began the preparation of a memoir on the Kiowa calendars, which was nearly completed at the end of the fiscal year, and has been assigned for publication in the seventeenth annual report.

As during past years, much attention has been given to photographing Indians and Indian subjects, and a small photographic laboratory has been maintained, through the aid of Mr. William Dinwiddie. During the winter advantage was taken of the presence of representative Indians in the national capital, and a number of portrait photographs were obtained, together with considerable genealogic information concerning various chiefs and leading men among several tribes.

SOCIOLOGY.

Except while occupied in administrative work, Mr. W J McGee, ethnologist in charge of the Bureau, has been carrying forward researches relating to the social organization of the Indian tribes. His work is based on the voluminous records in the archives of the Bureau and on observations especially among the Papago and Seri Indians. It has been the aim to render this work fundamental, and to this end the primary characteristics of mankind as distinguished from lower organisms have been considered with especial care, and the studies of the Seri Indians have been particularly fruitful. Among the results of the researches there may be mentioned (1) an analysis of the beginning of agriculture, (2) the recognition of the beginning of zooculture, (3) a study of the growth of altruistic motive, and (4) an examination of early stages in the development of marriage. These results are incorporated partly in a preliminary memoir on the "Siouan Indians" printed in the fifteenth annual report, partly in several administrative reports, and partly in an address published in the Smithsonian annual report for 1895.

It may be noted summarily that the researches concerning the beginning of agriculture indicate that this important art originated independently in different desert regions, and was at first merely an expression of a solidarity into which men and lower organisms were forced by reason of the environmental conditions characteristic of the desert. Later the art was raised to a higher plane through the gradual development of irrigation, and still later it was extended into areas in which irrigation was not required. The researches concerning zooculture serve to define a stage antecedent to domestication, as that term is commonly employed, in which the relations between men and animals are collective rather than individual, and in which the men and animals become mutually tolerant and mutually beneficial, as when the coyote serves as a scavenger and gives warning, in his own cowardly retreat, of the approach of enemies. Later, such of the tolerated animals as are thereby made more beneficial are gradually brought into domestication, as was the coyote-dog among many Indian tribes, the turkey among some, and the reindeer among certain Eskimo. The researches concerning the development of human motive are involved in the study of primitive law, and indicate that regulations concerning conduct are framed by the elders in the interest of harmony and collective benefit, and that these regulations are enforced until their observance becomes habitual, when the habit in turn grows into motive. In some other directions, also, substantial progress has been made in the study of the organizations and institutions of the American Indians.

LINGUISTICS.

During a considerable part of the year the Director has been occupied in researches concerning several characteristics of the American Indians, with the view of developing a system of classification so complete as to indicate not only the affinities of tribes and stocks among each other but the general affinities of the native American people and their position among the races of men as well as among other living organisms. In the course of this work much thought has been given to the subject of Indian language, and the rich collections of linguistic material in the archives of the Bureau have been scanned anew. It was the immediate purpose of this study to trace the development of various languages in such manner as to educe the laws of linguistic evolution. Satisfactory progress was made, and a considerable body of manuscript was prepared, while a preliminary publication was presented during the year in the form of an address delivered in the United States National Museum May 23, 1896, entitled "The Relation Between Institutions and Environment," and printed in the Smithsonian Report for 1895. The records indicate that the four or five dozen distinct linguistic stocks in this country have been rendered more or less composite by the blending of peoples: the researches seem to show that a still larger number of distinct languages were originally developed independently, in small, discrete groups, which gradually combined into larger tribes and confederacies, and sometimes grew so large as again to subdivide and spread over vast areas; and in various other directions these researches have been found to throw light on the characteristics and relations of the Indians.

Dr. Albert S. Gatschet has been continuously employed in the collection and study of linguistic material pertaining to the Algonquian stock. During July he utilized the services of Mr. William Jones, a mixed-blood Sauk of exceptional intelligence, a pupil at Philips Academy, Andover. Although he has been absent from his tribe for some time, he was able to convey to Dr. Gatschet a large amount of new material. About the middle of October Dr. Gatschet visited the survivors of the Miami Indians at Peru, Ind., and afterward proceeded to Miami town on Osage River, Indian Territory, now the center of the Peoria confederacy. At both places he was able to obtain extensive collections relating to the language and mythology of the people. During the remainder of the fiscal year he was occupied in arranging the new material and in comparing it with other Algonquian records, and made considerable progress in the preparation of a comparative Algonquian vocabulary.

Mr. J. N. B. Hewitt was employed in the early part of the year in applying the laws of linguistic development to the Iroquoian stock, and thereby tracing the affinities and prehistoric growth of this extensive and important group of American Indians. Through this study he was able to ascertain the order in which different members of the group differentiated, and either separated from the main body or developed distinct organization. Representing the Iroquoian body as the trunk of a genealogic tree, it appears that the lowest branch is represented by the Cherokee and the second and third by the Huron and Seneca-Onondaga, the several tribes represented by the uppermost branches being but slightly differentiated. Thus the linguistic history of the Iroquoian stock is one of differentiation and division, probably combined with assimilation from other stocks. It may be observed that this history is parallel to that wrought out for the Siouan stock by Dorsey and that which Gatschet is now tracing in the Algonquian stock; but this apparently aberrant course of linguistic evolution in certain instances is in no way inconsistent with the general course of the development of language, which tends toward unity through the combination and assimilation of the various tongues. Subsequently Mr. Hewitt was occupied in analyzing and scheduling the vocabulary of the Tubari language, collected in northern Mexico by Dr. Carl Lumholtz, and in preparing the matter for publication. The closing months of the year were spent in cataloguing manuscripts and other material stored in the fireproof vaults of the Bureau.

MYTHOLOGY.

Mrs. Matilda Coxe Stevenson continued the study and elaboration of her records concerning the mythology and ceremonials of the Zuñi Indians, and practically completed her monograph on this subject. The Pueblo Indians, and especially the Zuñi, are characterized by an extraordinary subserviency to belief and ritual. Before her connection with the Bureau Mrs. Stevenson became intimately acquainted with the Indians of several pueblos and with their peculiar fiducial customs, and has consequently had unprecedented opportunity for the study of observances and esoteric ceremonials, and it has been her aim to record the details of her observations with pencil and camera so fully as to perpetuate these mysteries for the use of future students. In nearly every respect she regards her records concerning the Zuñi as complete. At the end of the fiscal year her monograph was finished with the exception of a single chapter, the material for which was incomplete. It was planned to have this material collected during July and August, 1896.

During the greater part of the year Mr. Cushing's work in mythology was suspended, as he was engaged in general archeologic work. During the early part of the year, however, he spent several weeks in combining the records of archeology, mythology, and modern custom bearing on the evolution and multifarious uses of the arrow, and incidentally on the invention of the bow. His researches illustrate well not only the great importance of the arrow as a factor in human development, but also the way in which primitive peoples think, act, and evolve. The final report on this subject is not yet complete, but a preliminary statement of results was made public in the form of a vice-presidential address before the American Association for the Advancement of Science at the Springfield meeting, 1895.

PSYCHOLOGY.

It has not been found expedient in the Bureau to extend the researches to the somatology of the Indians, and all the material pertaining to this subject has been turned over to another branch of the Federal service; but it has been found impossible to trace the development of the arts and institutions, beliefs and languages of the aborigines without careful study of primitive modes of thought, and much attention has been given by the Director and some of the collaborators to the subject of psychology, as exemplified among the Indians. The researches in this direction have been carried forward during the year in connection with the work in classification of the Indians, and considerable material has been accumulated for publication in future reports.

BIBLIOGRAPHY.

The bibliographic work, which has been continued for several years, practically closed with the last fiscal year, and finally terminated, so far as the original plan is concerned, with the death of James Constantine Pilling on July 26. The bibliography of the Mexican languages was left in a nearly finished condition; but it has not yet been found practicable to complete this work and prepare it for the press.

PUBLICATION.

Satisfactory progress has been made during the fiscal year in the editorial work of the Bureau, which has been conducted chiefly by Mr. F. W. Hodge.

The manuscript of the fourteenth annual report was sent to press toward the close of the last fiscal year, the first proofs were received on January 25, 1896, and by the close of the fiscal year the body of the volume was nearly all in type. This report, which is to be published in two volumes, making about 1,200 pages, comprises, in addition to the report on the operations of the Bureau and an exhaustive index, three memoirs—"The Menomini Indians," by Walter J. Hoffman, and "Coronado's Expedition in 1540–1542," by George Parker Winship, occupying the first part; the second

part containing a paper on the "Ghost-Dance Religion," by James Mooney. This report, like the preceding volumes of the series, will be amply illustrated, and it is expected that it will be ready for distribution before the close of the calendar year.

Although the manuscript of the fifteenth annual report was transmitted to the Public Printer on June 14, 1895, no text proof was received during the fiscal year; the proofs of the illustrations have, however, been received and approved. The accompanying papers of the fifteenth report comprise "Stone Implements of the Potomac-Chesapeake Tidewater Province," by W. H. Holmes; "The Siouan Indians," by W J McGee, a paper complementary with and introductory to a posthumous memoir on "Siouan Sociology," by James Owen Dorsey; "Tusayan Katcinas," by J. Walter Fewkes, and "The Repair of Casa Grande Ruin, Arizona, in 1891," by Comos Mindeleff. The volume contains upward of a hundred plates, in addition to numerous figures in the text, all of which have been engraved.

The manuscript of the sixteenth annual report was sent to the Government Printing Office on September 27, 1895. The illustrations have all been engraved, but no proof of the text had been received at the close of the fiscal year. The accompanying papers of this report are "Primitive Trephining," by Manuel Antonio Muñiz and W J McGee; "Cliff Dwellings of Canyon de Chelly, Arizona," by Cosmos Mindeleff, and "The Maya Day Symbol," by Cyrus Thomas.

The only volume published by the Bureau during the fiscal year was the thirteenth annual report, which was delivered by the Public Printer in May, and at once transmitted to the numerous correspondents of the Bureau throughout the world. This volume, for which the demand from students has been unusually large, contains, in addition to the Director's report of 59 pages, the following memoirs: (1) Prehistoric textile art of eastern United States, by William H. Holmes, pages 3–46, Pls. I–IX, figs. 1–28. (2) Stone art, by Gerard Fowke, pages 47–178, figs. 29–278. (3) Aboriginal remains in Verde Valley, Arizona, by Cosmos Mindeleff, pages 179–261, Pls. X–L, figs. 279–305. (4) Omaha dwellings, furniture, and implements, by James Owen Dorsey, pages 263–288, figs. 306–327. (5) Casa Grande ruin, by Cosmos Mindeleff, pages 289–319, Pls. LI–LX, figs. 328–330. (6) Outlines of Zuñi creation myths, by Frank Hamilton Cushing, pages 321–447.

Most of the material for the seventeenth annual report has been prepared for the printer, though the manuscript has not yet been transmitted. The accompanying papers comprise a memoir on "The Seri Indians," by W J McGee; the report by Dr. Fewkes on decorative pottery and other material from Arizona; Mr. Mooney's memoir on "Kiowa Calendars;" a special paper on "Navaho Houses," contributed by Cosmos Mindeleff, and the memoir on "Indian Land Cessions," prepared by C. C. Royce and revised by Dr. Thomas. The papers are fully illustrated by maps, photographs, and sketches. Like the fourteenth report, it will doubtless be bound in two volumes.

MISCELLANEOUS WORK.

Library.—It is the plan of the Bureau to maintain a small working library for the use of the collaborators, and it has grown slowly through accessions, acquired chiefly by exchange for reports, the growth barely keeping pace with the publication of anthropologic works. At the end of the fiscal year the library numbered 5,501 volumes, having increased by 472 volumes during the preceding twelve months. In addition, there was a proportionate accession of pamphlets and periodicals.

Illustrations.—The preparation of illustrations for the reports has been continued under the direction of Mr. DeLancey W. Gill. The drawings have been executed by a number of artists, while the photographs have been made chiefly by Mr. Dinwiddie. In addition to the photographic work required for the immediate illustration of reports, the various collaborators at work in the field are supplied with cameras, and make considerable numbers of photographs, by which their notes are supplemented and enriched, and many of these photographs are incorporated in subsequent

reports. Extensive series of photographs were made during the year by Dr. Fewkes in connection with his collections of pueblo pottery; by Mr. J. W. Mitchell, photographer for Mr. McGee in the Seriland expedition, and by Mr. Wells M. Sawyer, artist for Mr. Cushing in his Florida work.

Exhibits.—The Bureau cooperated with the National Museum in arranging the Smithsonian Institution exhibit in the Cotton States and International Exposition held at Atlanta during the autumn of 1895. An alcove in the Government building was allotted to the Bureau, and this was filled by the installation of six wall cases and four floor cases, together with a number of bulky objects arranged on top of the wall cases. This exhibit was so arranged as to illustrate the characteristics and modes of life of three tribes, viz: The Cherokee Indians, who formerly occupied the country in what is now northern Georgia, and whose descendants still live in western North Carolina only 150 miles from the site of the exposition; the Papago Indians, a little known though highly interesting tribe of peaceful Indians, occupying southwestern Arizona and northern Sonora; and the Seri Indians, a fierce and exclusive tribe of the Gulf of California, part of whom were found on their borderland and in the course of an expedition by the Bureau during 1894. In addition to the objects exhibited, there were in two wall cases illustrations of the physical characteristics and costumary of the Papago and Seri Indians. The former were represented by a group of life-size figures engaged in the manufacture of pottery—their typical industry. In the other case a life-size figure of a Seri warrior was introduced. The collections were supplemented by a series of twelve transparencies, made from photographs, showing the Papago and Seri Indians in characteristic attire, with their habitations and domestic surroundings. In the installation of this exhibit, primary attention was given to fidelity of representation rather than to artistic finish or grouping; and it is a source of gratification to observe that the exhibit attracted much attention during the progress of the exposition. It was awarded a grand prize, diploma, and gold medal.

NECROLOGY.

James Constantine Pilling, who died July 26, 1895, was a native of the national capital, where he was born November 16, 1846. He was educated in the public schools and Gonzaga College, and subsequently strengthened his predilection toward books by taking a position in a leading bookstore of the city; at the same time he studied the then novel art of stenography, in which he became remarkably proficient. At the age of twenty he became a court stenographer. His services soon came into demand among the Congressional committees and in different commissions employed in the settlement of war claims. In every instance his notable speed and accuracy were joined with even more notable discretion and straightforwardness that gained for him the esteem of all with whom he came in contact. His career as stenographer was in every respect exemplary, and his example served to hasten the general introduction, and at the same time to elevate the standard, of stenographic art as an aid in the transaction of the public business.

In 1875 Mr. Pilling was employed by the Director, then in charge of the geological and topographical surveys of the Rocky Mountain region, to aid in collecting native vocabularies and traditions, a task for which he was eminently fitted by reason of his phonetic and manual skill. In this service as in his earlier work he displayed not only high ability but signal strength of character. His connection with the survey was continued until that organization was brought to an end in 1879 by the institution of the United States Geological Survey to carry forward the geologic work and the Bureau of American Ethnology to continue the ethnologic researches; he was then transferred to the Bureau of Ethnology, where his work on the Indian languages was continued. During this period of connection with ethnologic work his studious habits were strengthened, and he developed great interest in

the literature relating to the Indians; and he readily adopted the suggestion of the Director to begin the preparation of a list of books and papers containing Indian linguistics. In this study the industry and accuracy which characterized his stenographic work were constantly displayed, and ever-increasing confidence was reposed in his trustworthiness. In connection with his stenographic and bibliographic work, he was intrusted with the supervision of the editorial work of the reports of the Rocky Mountain survey and the newly instituted Bureau, and in addition considerable clerical work fell to him; yet every duty was performed with alacrity, fidelity, and wisdom. Despite the multiplication of duties, his literary and bibliographic methods remained excellent, and even improved with time; and his conscientious care was so invariably manifested in his bibliographic work that his rapidly growing list came to be recognized as a standard from which it were bootless to appeal. It was during these years, from 1875 to 1880, that the foundation for Pilling's character as bibliographer was laid and securely established.

In 1881 the Director of the Ethnologic Bureau was made Director also of the United States Geological Survey, and Mr. Pilling was appointed chief clerk of the Survey, and the customary administrative duties were devolved on him. These duties were ever performed energetically yet judiciously, and withal so courteously and impartially as to gain for him the confidence of every collaborator in that rapidly growing Bureau. In this position he continued until June 30, 1892. During this period he served also as chief clerk of the Ethnologic Bureau in an eminently acceptable manner; and although his administrative work as the second officer in the two Bureaus might well have been regarded as sufficient to occupy all the energies of one man, he never forgot his bibliography, and so ordered his duties that few days passed without some addition to his list of books on Indian linguistics. Meantime his search for rare and little-known works brought him into correspondence with dealers, bibliophiles, missionaries on the outposts of civilization, travelers in Indian lands, and many others, and he frequently found it necessary to purchase books in order that their contents might be examined and their titles noted; and in this way he gradually accumulated a unique library—one of the richest collections of rare books relating to Indian tongues now in existence. In 1885 there was issued for the use of collaborators and correspondents of the Bureau, in a small edition, a quarto volume of nearly twelve hundred pages, entitled "Proof-sheets of a Bibliography of the Languages of the North American Indians, by James Constantine Pilling." This volume represented the results of Mr. Pilling's bibliographic work up to that date, and served as a basis for the classification, on the part of the Director, of the North American tribes by linguistic characters. The printing of this volume served to deepen the interest of the bibliographer in his task, and within a year or two the issue of a series of bibliographies relating to various Indian stocks or families was begun.

As time passed Mr. Pilling began to develop premonitory symptoms of locomotor ataxia, and his duties were varied, so far as the legal conditions controlling governmental bureaus permitted, in the hope of bringing relief; but despite every effort the malady increased. In 1892 he was relieved of his duties as chief clerk of the Geological Survey and the Bureau of American Ethnology, and was transferred to the latter Bureau and employed solely in continuing the bibliographic work. For a time he benefited by the transfer, and his duty was performed with great energy and continued skill and success, so that by the end of 1894 his bibliographies of the Eskimo, Siouan, Iroquoian, Algonquian, Athapascan, Chinookan, Salishan, and Wakashan languages were completed and printed. He was then engaged in the bibliography of the Indian languages of Mexico, and this was carried forward during the early months of 1895, even after its author had become practically helpless through the insidious and uncontrollable advance of a hopeless disease. This work was not finished.

The series of bibliographies prepared by Mr. Pilling are a monument to his memory

and a model for students. In thoroughness and accuracy of work they afford a bright example of American scholarship.

In personal character Mr. Pilling was above reproach. No man was more steadfast to his moral and intellectual convictions, which were held with that charity for others which is possible only to those who have strong and well-founded convictions of their own. The example and influence of his character will long remain on the institutions with which he was connected.

Respectfully submitted.

J. W. POWELL,
Director.

MR. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Appendix III.

REPORT ON THE TRANSACTIONS OF THE BUREAU OF INTERNATIONAL EXCHANGES FOR THE YEAR ENDING JUNE 30, 1896.

Sir: I have the honor to submit the following report upon the operations of the Bureau of International Exchanges for the fiscal year ending June 30, 1896:

The actual number of packages received from all sources for distribution during the year ending June 30, 1896, was 18,240 less than during the preceding year, although 540 names were added to the list of foreign correspondents and the domestic list was increased by 966.

During the year a large number of Government departmental publications, being within the weight limited by the postal regulations, have been forwarded direct by mail, whereas similar transmissions ordinarily pass through the Exchange Bureau. This fact is accountable in part for the decrease of the number of transmissions as compared with the preceding year.

TABULAR STATEMENT OF THE WORK OF THE BUREAU.

The work of the Bureau is succinctly given in the following table, prepared in accordance with the form used in preceding reports:

Transactions of the Bureau of International Exchanges during the fiscal year 1895–96.

Date.	Number of packages received.	Weight of packages received.	Correspondents June 30, 1896.				Packages sent to domestic addresses.	Invoices written.	Cases shipped abroad.	Letters received.	Letters sent.
			Foreign societies.	Domestic societies.	Foreign individuals.	Domestic individuals.					
1895.											
July	8,733	12,501	......	......	......	......	......	......	......	230	215
August	4,312	16,192	......	......	......	......	......	......	......	205	134
September	6,701	22,395	......	......	......	......	......	......	......	169	149
October	6,760	16,150	......	......	......	......	......	......	......	206	195
November	7,400	18,786	......	......	......	......	......	......	......	197	170
December	5,966	13,077	......	......	......	......	......	......	......	184	210
1896.											
January	9,092	21,787	......	......	......	......	......	......	......	170	249
February	8,431	18,038	......	......	......	......	......	......	......	209	154
March	5,996	19,607	......	......	......	......	......	......	......	192	205
April	8,215	19,051	......	......	......	......	......	......	......	167	133
May	4,444	13,321	......	......	......	......	......	......	......	215	311
June	12,828	67,826	......	......	......	......	......	......	......	223	246
Total	88,878	258,731	8,022	2,115	10,878	3,899	34,091	21,783	1,043	2,367	2,371
Increase over 1894–95	*a*18,240	*a*68,224	*a* 729	101	1,269	865	4,980	*a* 5,397	*a* 321	*a* 76	112

a Decrease

For comparison with previous years the following table will represent the growth of the service from 1890 to 1896:

	1889–90.	1890–91.	1891–92.	1892–93.	1893–94.	1894–95.	1895–96.
Number of packages received	82, 572	90, 666	97, 027	101, 063	97, 969	107, 118	88, 878
Weight of packages received	202, 657	237, 612	226, 517	200, 928	235, 028	326, 955	258, 731
Ledger accounts:							
Foreign societies	5, 131	5, 981	6, 204	6, 896	6, 991	8, 751	8, 022
Foreign individuals	6, 340	7, 072	7, 910	8, 554	8, 619	9, 609	10, 878
Domestic societies	1, 431	1, 588	2, 044	2, 414	1, 620	2, 014	2, 115
Domestic individuals	3, 100	4, 207	4, 524	5, 010	2, 993	3, 034	3, 899
Packages to domestic addresses	13, 216	29, 047	26, 000	29, 454	32, 931	29, 111	34, 091
Invoices written	16, 948	21, 923	23, 136	19, 996	20, 869	27, 180	21, 783
Cases shipped abroad	873	962	1, 015	878	905	1, 364	1, 043
Letters received	1, 509	2, 207	2, 323	2, 013	2, 166	2, 443	2, 367
Letters written	1, 625	2, 417	2, 752	2, 259	1, 904	2, 259	2, 371

EXPENSES.

The expense of the exchange system is provided in part by direct appropriation by Congress to the Smithsonian Institution for the purpose and in part by appropriations made to different Government Departments or Bureaus, either contingent or specific, for repayment to the Institution for a portion of the cost of transportation.

Even with the close economy necessarily exercised in the disbursement of the direct appropriations in support of the exchange service, the Institution would not have been able to transmit exchanges with requisite promptness or regularity had it not been for the revenue derived from the charge of 5 cents per pound weight made to Government Departments and Bureaus and to State institutions on their exchanges, both going and coming. This charge was authorized by the Board of Regents as far back as 1878, and has since been maintained. Though the appropriations have been increased from time to time, they have not kept pace with the growing demands of the service, and since its inauguration there has never been a time that the practice could have been abolished or even temporarily suspended.

The appropriation made by Congress to the Institution for the exchange service during the fiscal year 1895–96 was in the following language:

"For expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, seventeen thousand dollars."

The receipts and disbursements by the accounting officer of the Smithsonian Institution on account of international exchanges for the year immediately preceding July 1, 1896, were as follows:

RECEIPTS.

	Congressional appropriation.	Other sources.	Total.
Direct appropriation by Congress	$17, 000. 00		$17, 000. 00
Repayments from United States Government Departments		$2, 737. 43	2, 737. 43
Repayments from State institutions		271. 00	271. 00
Repayments from other sources		461. 29	461. 29
Balance advanced by Smithsonian Institution		98. 42	98. 42
Total	17, 000. 00	3, 568. 14	20, 568. 14

EXPENSES.

	From specific appropriation.	From other sources.	Total.
Salaries and compensation	$14,519.73	$325.00	$14,844.73
Freight	1,502.32	2,130.71	3,633.03
Printing	9.50	4.00	13.50
Postage	20.32	100.00	120.32
Stationery and supplies	193.03	605.44	798.47
Packing boxes		341.44	341.44
Traveling expenses	574.18		574.18
Incidentals		61.55	61.55
Balance to meet outstanding liabilities June 30, 1896	180.92		180.92
Total	17,000.00	3,568.14	20,568.14

The foregoing statement shows that the entire amount received from Government Bureaus and other sources was $3,469.72, which, added to the direct appropriation of $17,000, makes the aggregate income $20,469.72. This amount was insufficient to meet outstanding obligations, and the Institution was therefore called upon to advance the sum of $98.42.

CORRESPONDENTS.

The total number of correspondents of the Exchange Bureau now aggregates 24,914, an increase of 1,506 over last year; of this number, 18,900 are foreign and 6,014 are domestic, about 40 per cent of which being institutions and 60 per cent individuals. This entire list may be considered active, and for convenience each debit and credit account is kept on separate cards, easily discernible on account of using different colors, thus aiding greatly in expediting the work. These cards are assembled in geographical order, making them at all times accessible for quick reference.

The printing of a revised list of foreign correspondents deserves early consideration. In March, 1895, the Secretary authorized the preparation of a revised list, and Mr. Boehmer promptly perfected a card catalogue for that purpose, eliminating some duplications and adding many new names. Action upon the publication of the list, however, has not been approved for the reason that sufficient means in excess of amount necessary to meet current expenses have not been available.

INTERNATIONAL EXCHANGE OF OFFICIAL DOCUMENTS.

The number of official United States Government publications sent to the State libraries of foreign countries during the year in accordance with the act of Congress of 1867 and the Brussels treaty of 1886 was 15,458, and the number received from those sources and deposited in the Library of Congress was 8,038. The United States Government Departments have forwarded to their foreign correspondents 16,621 packages, and have received in return 10,512. Taken collectively, the packages of exchanges transmitted for the Government in all its branches aggregate 57 per cent of the entire number handled.

While the receipts from abroad for deposit in the Library of Congress have been much larger during the year than those reported for the fiscal year ending June 30, 1895, the increase has evidently been occasioned by large receipts from sources that made no shipments during the previous year, and the considerable increase can not therefore be considered permanent in character.

As the new building for the Library of Congress approaches completion and much-needed space will soon be available for accessions, a special agent should be sent abroad for the purpose of obtaining contributions, in order, if possible, to make the receipts more consistent with the shipments.

The exchange on account of Government Bureaus is shown in detail in the following table:

Statement of Government exchanges during the year 1895–96.

Name of Bureau.	Packages. Received for.	Packages. Sent by.
Smithsonian Institution	7,960	1,068
Astrophysical Observatory	2	....
Bureau of Ethnology	211	741
Bureau of International Exchanges	1	....
National Zoological Park	3	....
U. S. Agricultural Department	291	17
U. S. Botanic Garden	1	....
U. S. Bureau of American Republics	4	....
U. S. Bureau of Education	86	....
U. S. Bureau of Medicine and Surgery	6	....
U. S. Bureau of Navigation	6	....
U. S. Bureau of Ordnance, Navy Department	1	....
U. S. Bureau of Ordnance, War Department	3	....
U. S. Bureau of Statistics	23	....
U. S. Census Office	7	....
U. S. Coast and Geodetic Survey	97	20
U. S. Comptroller of the Currency	2	....
U. S. Congressional Library	8,038	....
U. S. Department of Labor	19	14
U. S. Department of Steam Engineering, Navy Department	2	....
U. S. Engineer Office	44	79
U. S. Entomological Commission	13	....
U. S. Fish Commission	61	560
U. S. General Land Office	2	....
U. S. Geological Survey	590	3,800
U. S. Hydrographic Office	81	....
U. S. Indian Affairs Office	8	....
U. S. Interior Department	17	1,437
U. S. Interstate Commerce Commission	23	247
U. S. Life-Saving Service	1	....
U. S. Light-House Board	2	1
U. S. Marine-Hospital Service	6	....
U. S. Mint—Director	3	....
U. S. National Academy	114	1,115
U. S. National Board of Health	2	....
U. S. National Museum	276	1,456
U. S. Nautical Almanac Office	18	33
U. S. Naval Intelligence Office	1	....
U. S. Naval Museum of Hygiene	1	....
U. S. Naval Observatory	125	16
U. S. Navy Department	8	....
U. S. Patent Office	70	4,250
U. S. President	1	....
U. S. Public Printer	....	15,458
U. S. Signal Service	44	....
U. S. State Department	17	....
U. S. Superintendent of Public Documents	1	3
U. S. Surgeon-General's Office (Army)	151	540
U. S. Surgeon-General's Office (Navy)	4	....
U. S. Treasury Department	10	....
U. S. Vice-President	1	....
U. S. War Department	17	....
U. S. War Records Office	....	199
U. S. Weather Bureau	75	1,025
Total	18,550	32,079

EFFICENCY OF THE SERVICE.

The exchange relations with Greece are still, as in the past two years, in an unsatisfactory condition, and at present no packages are forwarded to that country except those emanating from Government Bureaus and scientific contributions which as to size and weight are sufficiently within the requirements of the postal service to admit of their being forwarded direct by post.

The exchanges with Mexico also continue to be unsatisfactory, and the transmission of parliamentary documents is suspended pending the result of an effort now being made through diplomatic correspondence to establish a systematic exchange of publications by a responsible representative to be duly authorized by the Mexican Government. Publications of scientific bureaus and societies are forwarded direct by mail, however, as before stated.

The official exchange of public documents is also temporarily suspended with Japan, owing to the absence of a systematic provision for the proper conduct of the

work. The Japanese minister is in correspondence with his Government, and it is hoped satisfactory arrangements will soon be effected.

The increased appropriation for 1895-96 over previous years has enabled the Bureau to employ some additional assistance and to more expeditiously transmit the packages intrusted to it. The foreign service could, however, be made much more effective if the appropriation was sufficient to admit of forwarding cases by fast steamers instead of being compelled to rely upon slower conveyance as is now occasioned by forced economy.

No provision has yet been made in Congressional appropriations for the immediate exchange of parliamentary documents in accordance with the treaty concluded at Brussels in 1886, and for which the Secretary of State recommended that $2,000 be appropriated.

It is my pleasure to inform you of the efficiency of the employees of the Exchange Bureau, and to express my appreciation of the energy with which they uniformly endeavor to prevent the work from accumulating. I beg also to call your attention to the interest taken in all affairs of the Institution by its agents in Europe, Dr. Felix Flügel in Leipsic and Messrs. William Wesley & Son in London.

Below is a list of transportation companies and others that continue to aid the Institution to a marked degree in contributing free freight or charging only a minimum, and in otherwise disinterestedly aiding in the diffusion of knowledge:

LIST OF SHIPPING AGENTS AND CONSULS TO WHOM THE EXCHANGE SERVICE IS INDEBTED FOR SPECIAL COURTESIES.

American Board of Commissioners for Foreign Missions, Boston.
Anchor Steamship Line (Henderson & Bro., agents), New York.
Atlas Steamship Company (Pim, Forwood & Co.), New York.
Bailey, H. B., & Co., New York.
Börs, C., consul-general for Sweden and Norway, New York.
Boulton, Bliss & Dallett, New York.
Calderon, Climaco, consul-general for Colombia, New York.
Cameron, R. W., & Co., New York.
Baltazzi, X., consul-general for Turkey, New York.
Compagnie Générale Transatlantique (A. Forget, agent), New York.
Cunard Royal Mail Steamship Company (Vernon H. Brown & Co., agents), New York.
Consul-general for Chile, New York.
Hamburg-American Line (R. J. Cortis, manager), New York.
Hensel, Bruckmann & Lorbacher, New York.
Consul-general for Uruguay, Baltimore, Md.
Muñoz y Espriella, New York.
Navigazione Generale Italiana (Phelps Bros. & Co.), New York.
Netherlands American Steam Navigation Company (W. H. Vanden Toorn, agent), New York.
North German Lloyd (agents: Oelrichs & Co., New York; A. Schumacher & Co., Baltimore).
Obarrio, Melchor, consul-general for Bolivia, New York.
Pacific Mail Steamship Company (H. J. Bullay, superintendent), New York.
Pioneer Line (R. W. Cameron & Co.), New York.
Perry, Ed., & Co., New York.
Pomares, Mariano, consul-general for Salvador, New York.
Red Star Line (Peter Wright & Sons, agents), New York and Philadelphia.
Röhl, C., consul-general for Argentina, New York.
Royal Danish consul, New York.
Royal Portuguese consul-general, New York.
Ruiz, Domingo L., consul-general for Ecuador.
Stewart, Alexander, consul-general for Paraguay, Washington, D. C.

Toriello, Enrique, consul-general for Guatemala, New York.
White Cross Line of Antwerp (Funch, Edye & Co.), New York.

The following is a list of the Smithsonian correspondents abroad acting as distributing centers, or receiving publications for transmission to the United States:

Algeria: Bureau Français des Échanges Internationaux, Paris, France.
Argentina: Museo Nacional, Buenos Ayres.
Austria-Hungary: Dr. Felix Flügel, No. 9 Schenkendorf Strasse, Leipzig, Germany.
Brazil: Bibliotheca Nacional, Rio Janeiro.
Belgium: Commission des Échanges Internationaux, Rue du Musée, No. 5, Brussels.
Bolivia: University, Chuquisaca.
British America: McGill College, Montreal, and Geological Survey Office, Ottawa.
British Colonies: Crown Agents for the Colonies, London, England.
British Guiana: The Observatory, Georgetown.
Cape Colony: Colonial Secretary, Cape Town.
Chile: Universidad de Chile, Santiago.
China: Dr. D. W. Doberck, Government Astronomer, Hongkong; for Shanghai: Zi-ka-wei Observatory, Shanghai.
Colombia (U. S. of): National Library, Bogotà.
Costa Rica: Instituto Fisico-Geográfico Nacional, San José.
Cuba: Dr. Federico Poey, Calle del Rayo, 19, Habana, Cuba.
Denmark: Kongelige Danske Videnskabernes Selskab, Copenhagen.
Dutch Guiana: Surinaamsche Koloniale Bibliotheek, Paramaribo.
East India: Director-General of Stores, India Office, London.
Ecuador: Observatorio del Colegio Nacional, Quito.
Egypt: Société Khédiviale de Géographie, Cairo.
France: Bureau Français des Échanges Internationaux, Paris.
Germany: Dr. Felix Flügel, No. 9 Schenkendorf Strasse, Leipzig.
Great Britain and Ireland: William Wesley & Son, 28 Essex street, Strand, London.
Guadeloupe. (*See* France.)
Guatemala: Instituto Nacional de Guatemala, Guatemala.
Haiti: Secrétaire d'État des Relations Extérieures, Port-au-Prince.
Honduras: Biblioteca Nacional, Tegucigalpa.
Iceland: Islands Stiptisbókasafn, Reykjavík.
Italy: Biblioteca Nazionale Vittorio Emanuele, Rome.
Japan: Minister of Foreign Affairs, Tokyo.
Java. (*See* Netherlands.)
Liberia: Liberia College, Monrovia.
Maderia: Director-General, Army Medical Department, London, England.
Malta. (*See* Madeira.)
Mauritius: Royal Society of Arts and Sciences, Port Louis.
Mexico: Packages sent by mail.
Mozambique: Sociedade de Geographa, Mozambique.
Netherlands: Bureau Scientifique Central Néerlandais, Den Helder.
New Caledonia: Gordon & Gotch, London, England.
Newfoundland: Postmaster-General, St. Johns.
New South Wales: Government Board for International Exchanges, Free Public Library, Sydney.
New Zealand: Colonial Museum, Wellington.
Norway: Kongelige Norske Frederiks Universitet, Christiania.
Paraguay: Government, Asunçion.
Peru: Biblioteca Nacional, Lima.
Philippine Islands: Royal Economical Society, Manila.
Polynesia: Department of Foreign Affairs, Honolulu.
Portugal: Bibliotheca Nacional, Lisbon.
Queensland: Registrar-General of Queensland, Brisbane.
Roumania. (*See* Germany.)

Russia: Commission Russe des Échanges Internationaux, Bibliothèque Impériale Publique, St. Petersburg.
St. Helena: Director-General, Army Medical Department, London, England.
Salvador: Museo Nacional, San Salvador.
Servia. (*See* Germany.)
South Australia: Astronomical Observatory, Adelaide.
Spain: R. Academia de Ciencias, Madrid.
Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.
Switzerland: Central Library, Berne.
Tasmania: Royal Society of Tasmania, Hobarton.
Turkey: American Board of Commissioners for Foreign Missions, Boston, Mass.
Uruguay: Oficina de Depósito, Reparto y Canje Internacional de Publicaciones, Montevideo.
Venezuela: Museo Nacional, Caracas.
Victoria: Public Library, Museum and National Gallery, Melbourne.
Western Australia: Agent General, London.

Transmission of exchanges to foreign countries.

Country.	Date of transmission, etc.
Argentina	September 14, November 22, 1895; February 3, March 26, May 23, June 22, 1896.
Austria-Hungary	July 10, 30, September 7, October 28, November 12, 26, December 5, 14, 30, 1895; January 8, 27, February 7, 20, March 7, 16, April 9, 18, 22, May 1, 14, June 1, 22, 1896.
Belgium	July 12, August 19, November 4, December 6, 1895; January 10, March 18, 21, May 5, June 9, 23, 1896.
Bolivia	September 14, 1895; May 23, 1896.
Brazil	September 14, November 22, December 17, 1895; February 3, March 26, May 23, June 22, 1896.
British colonies	August 30, October 15, November 14, December 17, 1895; February 6, April 4, May 7, June 29, 1896.
Cape Colony	September 19, December 21, 1895; May 20, 1896.
China	September 23, 1895; January 3, May 21, June 24, 1896.
Chile	September 14, November 22, December 10, 1895; February 3, March 26, May 23, June 22, 1896.
Colombia	November 22, 1895; March 26, May 23, 1896.
Costa Rica	September 17, December 19, 1895; May 25, 1896.
Cuba	March 11, 1896.
Denmark	July 12, August 21, November 7, 1895; January 29, March 18, May 20 June 24, 1896.
Dutch Guiana	May 23, 1896.
East India	September 23, December 10, 1895; May 21, 1896.
Ecuador	May 23, 1896.
Egypt	September 19, 1895; May 20, 1896.
France and colonies	July 9, 17, 25, September 4, October 21, November 20, December 3, 1895; January 2, 13, 28, February 7, 18, March 10, 16, April 13, May 2, 16, June 4, 22, 29, 1896.
Germany	July 10, 17, 30, September 7, October 28, November 12, 26, December 5, 14, 30, 1895; January 8, 21, 27, February 7, 19, 20, March 7, 16, April 9, 18, May 1, 14, June 1, 22, 29, 1896.
Great Britain, etc	July 5, 17, 29, August 30, September 4, 23, October 15, November 1, 14, December 2, 9, 17, 26, 1895; January 7, 25, February 6, 27, March 14, 17, April 4, 17, 22, 28, May 7, 27, June 15, 29, 1896.
Guatemala	September 17, December 19, 1895; May 25, 1896.
Haiti	September 17, 1895.
Honduras	September 17, December 19, 1895; May 25, 1896.

Transmission of exchanges to foreign countries—Continued.

Country.	Date of transmission, etc.
Italy	July 10, 12, August 8, November 1, December 3, 18, 1895; March 2, 28, April 20, May 5, June 9, 23, 1896.
Japan	September 23, 1895.
Liberia	May 20, 1896.
Mexico	(By registered mail.)
New South Wales	July 1, November 11, 1895; January 13, March 31, June 17, 1896.
Netherlands and colonies	July 12, August 7, November 4, December 12, 1895; January 30, March 18, April 18, May 23, June 10, 24, 1896.
New Zealand	July 1, November 11, 1895; January 13, March 31, June 17, 1896.
Nicaragua	December 19, 1895.
Norway	July 12, August 21, November 7, 1895; January 29, March 21, May 19, June 10, 24, 1896.
Peru	September 14, November 22, 1895; February 3, March 26, May 23, June 22, 1896.
Polynesia	July 1, November 11, 1895; January 13, March 31, June 17, 1896.
Portugal	July 12, August 20, November 7, 1895; January 31, March 21, May 9, June 24, 1896.
Queensland	July 1, November 11, December 9, 1895; January 13, March 31, May 7, June 17, 29, 1896.
Roumania	(Included in Germany.)
Russia	July 11, August 6, October 31, December 4, 1895; January 9, March 4, 24, April 14, May 4, June 8, 23, 1896.
Salvador	September 17, December 19, 1895; May 25, 1896.
Servia	(Included in Germany.)
South Australia	July 1, November 11, 1895; January 13, March 31, June 17, 1896.
Spain	July 12, August 19, November 7, December 17, 1895; January 31, March 20, May 16, 1896.
Sweden	July 11, August 6, 15, October 31, December 4, 1895; January 9, March 4, 24, April 14, May 4, June 8, 23, 1896.
Switzerland	July 11, August 13, November 6, December 10, 1895; January 3, March 19, April 21, May 18, June 17, 29, 1896.
Tasmania	January 25, 1896.
Turkey	December 10, 1895, June 24, 1896.
Uruguay	September 14, November 22, 1895; February 3, May 23, June 10, 24, 1896.
Venezuela	September 14, November 22, 1895; March 26, May 23, 1896.
Victoria	July 1, November 11, 1895; January 13, March 31, June 17, 1896.
Western Australia	January 25, 1896.

The distribution of exchanges to foreign countries was made in 919 cases, representing 218 transmissions, as follows:

Argentina	20	Mexico (by mail).	
Austria-Hungary	47	Natal	1
Belgium	30	New South Wales	13
Bolivia	2	Netherlands	18
Brazil	12	New Zealand	9
British colonies	9	Nicaragua	2
Cape Colony	3	Norway	13
China	5	Peru	6
Chile	8	Polynesia	5
Colombia	3	Portugal	7
Costa Rica	4	Queensland	31
Cuba (by mail).		Roûmania (included in Germany).	
Denmark	10	Russia	43
Dutch Guiana	1	Salvador	3
East India	9	Servia (included in Germany).	
Ecuador (by mail).		South Australia	6
Egypt	2	Spain	10
France and colonies	93	Sweden	30
Germany	145	Switzerland	28
Great Britain	220	Tasmania	1
Guatemala	3	Turkey	2
Haiti	1	Uruguay	6
Honduras	3	Venezuela	4
Italy	48	Victoria	14
Japan	4	Western Australia	2
Liberia	1		

Shipments of United States Congressional publications were made on October 7, 1895 and January 24 and May 13, 1896, to the Governments of the following-named countries:

Argentina.	Colombia.	New South Wales.	Spain.
Austria.	Denmark.	New Zealand.	Sweden.
Baden.	France.	Norway.	Switzerland.
Bavaria.	Germany.	Peru.	Tasmania.
Belgium.	England.	Portugal.	Turkey.
Buenos Ayres, Province of.	Haiti.	Prussia.	Uruguay.
Brazil.	Hungary.	Queensland.	Venezuela.
Canada (Ottawa).	India.	Russia.	Victoria.
Canada (Toronto).	Italy.	Saxony.	Würtemberg.
Chile.	Netherlands.	South Australia.	

Shipments to Greece, Japan, and Mexico are withheld for the present.

RECAPITULATION.

	Cases.
Total Government shipments	124
Total miscellaneous shipments	919
Total shipments	1,043
Total shipments last year	1,364
Decrease from last year	321

HISTORY OF THE EXCHANGE SERVICE.

By W. I. Adams.

The following history of the exchange service and its methods has been prepared by Mr. W. I. Adams from the archives of the Institution:

It seems altogether appropriate, while the Smithsonian Institution is commemorating the fiftieth year of its usefulness, to succinctly review the progress and accomplishments of its system for the exchange of the duplicate copies of literary and scientific publications from the beginning. Though but a subordinate branch of the Institution, the division of exchanges has done a large part in the increase and diffusion of knowledge, and materially assisted in the promotion of the object for which the Institution was established by its founder.

The forwarding by the Smithsonian Institution of its publications and annual reports to other scientific institutions and to individuals interested in science throughout the world was inaugurated almost at the very commencement of these publications, under a plan of procedure adopted by the Board of Regents December 8, 1847, upon the recommendation of Professor Henry, and in exchange the Institution solicited the scientific works published by its correspondents.

The details attendant upon this important function of the Institution were in the beginning supervised by Professor Henry, and so fully did they command his attention that not a little of the work was done by him personally, until July, 1850, when Professor Baird was appointed Assistant Secretary of the Institution, and almost immediately assumed direct charge of the exchanges.

Mr. George H. Boehmer, in his History of the Smithsonian Exchanges compiled to 1881, recites the fact that other attempts had been made for the exchange of literary and scientific publications, notably by the Royal Library of France in 1694, and in the United States early in the present century by the American Philosophical Society, founded in Philadelphia in 1743, and by the American Academy of Arts and Sciences, founded in Boston in 1780. The prime object in each case cited was the ultimate enrichment of its own library by reciprocal exchange, while the results desired by the Smithsonian Institution were not solely for the purpose of increasing its collection, but for the diffusion of knowledge among men.

So favorably did Professor Henry's plan impress scientists that a committee was appointed by the American Academy of Arts and Sciences to consider its methods in detail, and on December 7, 1847, the committee reported as follows:

"It can scarcely be doubted that an important impulse would be given by the Smithsonian Institution in this way to the cultivation of scientific pursuits, while the extensive and widely ramified system of distribution throughout the United States and the world would insure them a circulation which works of science could scarcely attain in any other way."

At the commencement of its exchange system the Institution was much annoyed by the excessive expense and troublesome delays caused by the requirements of the United States custom-house service, and no relief was felt until, after earnest and concerted effort, Congress was led to adopt the enlightened policy of admitting through the custom-houses free of duty scientific publications from foreign countries addressed to the Smithsonian Institution, either for its own use or as contributions to learned societies and institutions throughout the United States.

This appropriate act of the American Congress stimulated foreign scientific societies to interest their Governments to the same end. Among the first to take active steps in this direction was England.

On March 19, 1852, Mr. Edward Sabine, vice-president and treasurer of the Royal Society, wrote Professor Henry, in reply to his letter urging action by the Royal Society in the same direction, saying:

"The subject has since been brought by the Earl of Rosse under the consideration of Her Majesty's Government, who have shown, as might be expected, much readiness to meet in the same spirit the liberal example which has been set by the United States, in exempting free of duty scientific books sent as presents from this country

to the Smithsonian Institution, and through that institution to other institutions and to individuals cultivating science in the United States."

The sentiments thus expressed, although duly presented to Parliament, did not at once meet with results entirely satisfactory, though duties were remitted on books not foreign reprints of British copyrights. It was but a short time, however, before the generous cooperation of the Royal Society and the course recommended by it to the Government of Great Britain had its effect, and subsequently all packages from the Smithsonian Institution were admitted to the English ports free of duty, not only those bearing addresses in Great Britain, but to many places on the continent of Europe and the East Indies.

The matter of admitting exchanges free of duty having been satisfactorily adusted with the Governments of the United States and Great Britain, and after thus establishing a precedent, other Governments, recognizing the desirability of the plan, soon adopted like measures, and in the Smithsonian Report for the year 1854 the Secretary stated:

"There is no port to which the Smithsonian parcels are shipped where duties are charged on them, a certified invoice of contents by the Secretary being sufficient to pass them through the custom-house free of duty. On the other hand, all packages addressed to the Institution arriving at the ports of the United States, are admitted, without detention, duty free. This system of exchange is, therefore, the most extensive and efficient which has ever been established in any country."

The establishment of the Smithsonian exchange system soon became so widely known that the increased responsibilities and augmented expense threatened a drain upon the resources of the Institution to such an extent as to be alarming, and seemed to indicate a probable necessity of curtailing in some manner the expense of the task it had undertaken single-handed.

In 1855, with a view to diminishing, if possible, a part of the expense of the exchange system, letters were written to the principal transportation companies setting forth the nature of the undertaking, and, in consideration of the great benefit derived from the service, asking that they consider the subject of a reduction of rates. The replies received from nearly all the companies addressed were gratifying in the extreme—some consented to charge merely a nominal rate, while others cheerfully offered to transport exchanges free of any charge whatever.

With this generous assistance of the transportation companies, the Institution was enabled to continue the work and to maintain the system for the time being, notwithstanding the growing demands upon it.

The cooperation of the Department of State has been of incalculable value in the furtherance of the aims of the Institution in the diffusion of knowledge, and the results attained would have been difficult to surmount had it not been for the intelligent and courteous aid contributed by the representatives of the diplomatic and consular service in all parts of the world. The same consideration is due to the diplomatic representatives of foreign Governments residing in Washington, many of whom have not only done their utmost to aid their countrymen in obtaining the most advanced ideas of scientists throughout the world, but have been personally interested in scientific study.

In no field of international exchange of the products of effort is reciprocity so energetically demonstrated as in the promulgation of scientific research and higher education. The history of the Smithsonian exchanges demonstrates the far-reaching influence of study to such an extent as to make it impossible to conceive of the magnitude to which the service may attain and the results that must necessarily follow to the benefit of mankind.

Although on several occasions subsequent to 1840 special measures were adopted by Congress for the foreign distribution of special Government publications in exchange for similar works of other countries to be deposited in the Library of Congress, no general action was taken until 1867, when the following act was passed:

"*Resolved by the Senate and House of Representatives of the United States of America Congress assembled*, That fifty copies of all documents hereafter printed by order

of either House of Congress, and fifty copies additional of all documents printed in excess of the usual number, together with fifty copies of each publication issued by any Department or Bureau of the Government, be placed at the disposal of the Joint Committee on the Library, who shall exchange the same, through the agency of the Smithsonian Institution, for such works published in foreign countries, and especially by foreign Governments, as may be deemed by said committee an equivalent; said works to be deposited in the Library of Congress.

"Approved March 2, 1867."

It will be observed from the text of the law that the primary object of the act was to secure for the Library of Congress promptly, and with regularity, the official publications of foreign countries concerning legislation, jurisprudence, commerce, manufactures, agriculture, statistics, etc.

No appropriation was made, or even intimated, for this service, but as several months and perhaps a year would elapse before a sufficient number of documents would accumulate to admit of a systematic transmission, a circular letter was mailed through the official channel of the Department of State for the purpose of ascertaining what Governments would cooperate in the proposed arrangement. In due course so many foreign Governments accepted the proposition as to insure its success, though some countries were derelict in specifying to whom or in what manner the cases should be forwarded, it being understood that they would be delivered free of freight charges to any place in Washington or New York that might be designated.

These delays in consummating the desired plan were primarily due to the absence of concerted action in designating proper officers or establishing bureaus in different countries and providing sufficient means for defraying the attendant expenses. Though supported by the leading men in literature and science throughout the world, it was a slow process to obtain Government aid in the several countries most interested in the movement.

Several attempts were made by the Institution to induce Congress to assist in defraying the expense incurred in the distribution of Government publications, and also to obtain aid in the distribution of works upon scientific and literary subjects, the entire expense of which having in the year 1876 exceeded $10,000, or one-fourth of the income of the Institution, and was threatening a curtailment of expenses and serious impediment to research in its several scientific branches.

The persistent efforts of scientists and the growing interest manifested by the various Governments resulted in the holding of an International Congress in Paris during the months of August and September, 1875, at which were present several hundred scientists from all parts of the globe, and representing the following National Governments: Austria-Hungary, Belgium, Chile, Dominican Republic, France, Germany, Italy, Hungary, Norway, Portugal, Roumania, Russia, Spain, Sweden, Swiss Confederation, Turkey, and the United States. As a result of this conference the following plan for the international exchange of scientific publications was proposed and unanimously adopted:

"The undersigned delegates propose to request their respective Governments to organize in each country a central bureau, whose duty it shall be to collect such cartographic, geographic, and other publications as may be issued at the expense of the State, and to distribute the same among the various nations which adopt the present programme.

"These bureaus, which shall correspond directly with each other, shall serve to transmit the international scientific communications of learned societies.

"They shall serve as the intermediate agents for the procurement, on the best possible terms, of books, maps, instruments, etc., published or manufactured in each country, and desired by any of the contracting countries.

"Each country shall transmit at least one copy of its national publications to the other contracting countries."

In order to formulate the general plan adopted by the International Congress into tangible form to admit of more definitely arriving at the desired conclusions by the different countries interested, Baron de Vatteville was charged by his colleagues with the duty of forming at Paris a commission of exchanges, which, on January 29, 1876, adopted a code of rules, a copy of which was duly transmitted to Professor

Henry through the Department of State, asking for an expression of opinion as to its feasibility. The plan provided that each Government should designate a representative bureau for the administration of all the affairs pertaining to exchanges.

After extensive correspondence between the commission of exchanges at Paris, the Secretary of State, and the Secretary of the Smithsonian Institution with regard to the position this country would take in the organization of a proposed exchange bureau, it was finally made apparent that the Secretary of State was anxious to make the Smithsonian Institution the Government's official representative in the matter, its experience during more than a quarter of a century making it unqualifiedly the most efficient agency. The great expense, already burdensome to the Institution, and which must necessarily be largely increased by assuming the duties of the official medium of exchange of the Government, caused a renewal of effort in the direction of obtaining financial assistance from Congress, and the Department of State recommended that Congress should make an appropriation of $7,000 in aid of the Institution for the year of 1881. An allowance, however, of $3,000 only was granted. Even that amount was of great assistance, and admitted of the assumption that annual appropriations would follow in course.

The precedent of making Congressional appropriations in support of international exchanges thus being established, appropriations were thereafter made yearly, and in proportion more nearly commensurate with the growing demands of the service.

Although the act providing for the distribution of fifty copies of all Government publications was approved in 1867, the delay previously noted prevented their shipment abroad until 1873, since which time cases have been forwarded at comparatively regular intervals on an average of three cases each year, the parliamentary publications forwarded to the Smithsonian Institution in exchange being invariably for the Library of Congress.

Subsequent conferences held at Brussels in 1877 and 1880, and again in 1883, tended to more fully perfect the plan inaugurated at the Paris congress. The articles of agreement adopted at the conference in 1883 were referred by the Department of State to the Smithsonian Institution for review, and on March 15, 1886, another conference was called at Brussels, at which the articles were signed by duly appointed diplomatic delegates and laid before Congress, with the result that the agreement was approved and made the subject of a proclamation by the President January 15, 1889. The countries becoming parties to this agreement were Belgium, Brazil, Chile, Portugal, Servia, Spain, Switzerland, and the United States.

The second agreement, adopted by the same convention and by the same countries, with the exception of Switzerland, provided for the immediate transmission of parliamentary journals and documents to the other countries signing the agreement as soon as they were published. Uruguay and Peru subsequently became parties to the agreement, making a total of ten States under treaty obligations to maintain exchange relations.

The first treaty, so far as this country was concerned, did not change the existing practice of the exchange service as conducted by the Smithsonian Institution. The second treaty, providing for the immediate exchange of parliamentary journals, has not been made effective on the part of this Government through lack of action by Congress, first, by not placing the necessary documents at the disposal of the exchange bureau, and second, by not providing financial aid for carrying on the work; nor, in fact, has this treaty been fully complied with by any of the contracting Governments.

Although England, France, Germany, and Russia, it will be noticed, did not become parties to the Brussels treaties, special exchange arrangements were made between these countries and the United States under the act of Congress of 1867, and have since been successfully conducted.

In France and Russia exchange bureaus are supported as a part of the administrative functions of their respective Governments, while between England and Germany and the United States special arrangements have been made for the exchange of parliamentary publications.

Although exchange relations have been established with nearly all civilized

nations, the quantity of publications received has not, with the possible exception of England, compared favorably with the quantity sent. This inequality may perhaps be explained by the fact that no country publishes as liberally as the United States, and hence has fewer duplicate copies to offer in exchange.

During the past ten years an average of about thirty-five boxes of official publications of the United States Government have been forwarded to each of forty-three countries, the total number of publications thus sent being 227,400, or an average of 5,300 to each Government, while it is estimated that but 43,169 packages have been received from all foreign countries for the Library of Congress during the same period.

It is hardly equitable to use the above figures in comparison, as the outgoing publications are of actual record, while exchanges from foreign countries are often received in packages containing several pamphlets or volumes, and the actual number of publications can not be ascertained, as the packages are not opened in the exchange bureau, and, furthermore, owing to the crowded condition of the rooms occupied by the Library of Congress the boxes for several years arriving intact have not been opened for inspection and classification pending the removal of the Library to its new building.

As before mentioned, the entire expense of supporting the Smithsonian exchange service was borne by the Smithsonian fund from 1846 to 1881. The cost of the service for the five years from 1846 to 1850, inclusive, was $1,603. The next year, 1851, the expense was materially increased, being $2,010.49. In 1868 it had risen to $4,870.72, and in 1876 to $10,199.10. By the assistance from Congress in appropriating $3,000 in aid of the exchange service in 1881, the expense to the Institution was reduced to $7,467.84 for that year.

Although free freight had been granted by many transportation companies, both at home and abroad, and duties had been remitted everywhere, and although learned societies throughout the world had cooperated with the Institution to a marked degree, the expense to the Institution to 1881 had aggregated $141,308.96.

The National Government, although increasing its appropriations from time to time, has not entirely supported the exchange bureau, even in later years. During the period that Congressional appropriations have been effective the Smithsonian has been compelled to advance from its limited income an aggregate of $45,175.82 for the transportation of Government documents, which amount has not been refunded by Congress.

The rules under which the exchange bureau is conducted provide, in addition to the distribution of official publications of this Government to State libraries of foreign countries, for the forwarding of publications of literary and scientific societies and individuals as donations to correspondents in foreign countries and intended as exchanges, for which like contributions are expected in return.

No reimbursement is exacted from scientific societies, institutions of learning, or individuals when their contributions for foreign distribution are delivered at the Institution, domestic charges prepaid. In order to prevent an overtaxation upon the resources of the Institution, its Regents in 1878 authorized a charge to the bureaus of the National Government and to State institutions of a part of the expense incurred, both on incoming and outgoing exchanges, and the uniform rate in such instances of 5 cents per pound weight was adopted and has since been maintained.

Packages when delivered to duly authorized foreign agents for transmission to the United States are also forwarded without any expense to the contributor, and upon arrival at the Institution are entered and forwarded to destination by registered mail under frank. The franking privilege is not only employed in the United States, but also in sending packages to Canada and Mexico.

The above is in brief an explanation of the method employed in the transmission of exchanges between the United States and foreign countries. The procedure which should be invariably pursued by contributors is more particularly illustrated in the following:

Packages should be enveloped in stout paper and secured with strong twine, each

package not exceeding one-half of one cubic foot in bulk; they should be addressed legibly and as fully as possible without using abbreviations, and if an acknowledgment is required a blank receipt should be inclosed. When a consignment is complete all packages should be inclosed in boxes and forwarded by freight to the Smithsonian Institution, carriage prepaid. Before delivering consignments to transportation companies a list of names and addresses corresponding to those on packages should be forwarded by mail to the Smithsonian Institution, or to the foreign distributing agent of the Institution, according as the transaction may be of domestic or foreign origin. This procedure not only serves as a means for verifying each package when received, and enables the Institution to trace consignments if not delivered after a reasonable time has elapsed, but forms a permanent record for future reference.

Upon the receipt at the Institution of a consignment the entire transaction is given an invoice number, which serves as a basis for all entries made in connection with its distribution, and when debiting institutions or individuals to whom packages are addressed the corresponding invoice number is used, thereby avoiding the necessity of writing the name of the donor on each card. After all entries are made the books are packed in boxes and are forwarded by freight to the agents of the Institution abroad or to the distributing bureaus in foreign countries that have been designated to act in such capacity. In each package a receipt card is inserted bearing the invoice number assigned to each particular contribution, and when, as is often the case, several individual contributions are assembled in one package bearing a single address, the card inserted bears all the invoice numbers of the contents of that package. It is of the utmost importance that these cards should be receipted and returned to the Institution without delay as evidence of proper delivery, and as each acknowledgment is noted, a habitual failure in this regard may give rise to a doubt of delivery and subsequent packages may be returned to the contributors as undeliverable.

Packages received from abroad for distribution in the United States are treated in the same manner, and similar receipts are inclosed in parcels, which are returnable to the Institution under frank. These cards are, for the purpose of preventing confusion, of a color unlike those forwarded with packages for foreign distribution.

Purchased books, instruments, and natural history specimens (whether purchased or presented) are not accepted for transmission by the Institution or its agents without special permission in each instance.

Respectfully submitted.

W. W. KARR,
Acting Curator of Exchanges.

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

APPENDIX IV.

REPORT OF THE SUPERINTENDENT OF THE NATIONAL ZOOLOGICAL PARK.

SIR: I have the honor to submit the following report of the operations of the National Zoological Park for the fiscal year ending June 30, 1896:

Considerable attention has been paid during the year to the improvement of the grounds and the construction of roads authorized by Congress. The principal road of the park, which runs from the Quarry road westward to Connecticut avenue extended, has been improved over a part of its course by a good layer of macadam. It would have been well to have completed the macadamizing, but the funds at the disposal of the park did not permit this, and it will be deferred until next year. Work has been continued upon the driveway that proceeds from the Woodley road into the park. It will be remembered that the Woodley road lies so far above the level of the park that the construction of this driveway made necessary a heavy filling of earth. This is very unsightly, as the slopes are abrupt and difficult to modify by planting. If it is to remain where it now is, a sufficient amount of earth should be added to make the slopes easy and natural. The amount appropriated was insufficient to complete the fill so as to make an easy grade and neither macadam nor gutters have been provided, so that the road washes badly during the winter storms and is impracticable for pleasure driving during wet and freezing weather. It is, however, passable from the Woodley Bridge as far as Rock Creek.

It has been decided to restore the old Adams Mill road upon practically its former line. The configuration of the ground forbids making this the ordinary width of the roads of the park, the hillside on which it is built being quite steep at certain places, but a satisfactory driveway can be constructed. The survey of this work was completed and a contract for it prepared before the close of the fiscal year. The road will be well macadamized, with a top dressing of pulverized limestone. Retaining walls will be built where necessary, and the whole will be properly guttered and protected.

A number of interesting features have been added to the park, either for the purpose of beautifying it or for the convenience and accommodation of the animals. Two small fish ponds have been built near the Quarry road entrance, the banks in the neighborhood of the seal pond have been dressed and planted, and the débris from the intercepting sewer has been removed.

The accompanying illustrations show what has been done in preserving the native beauty of the Park. The first of these shows a rustic bridge formed of bowlders thrown across a little chasm cut out by a small stream that falls into Rock Creek. This has taken the place of an unsightly wooden bridge. Another picture shows where a small artificial pond for waterfowl empties into Rock Creek. The great advantage of such treatment is in the fact that it harmonizes with the surrounding scenery, and the visitor need not realize that any interference with the natural features has occurred, while the surface after treatment presents a striking contrast with the raw and denuded condition of those localities where engineering work has been carried on without regard to final effect.

The principal animal house has been greatly improved by the construction of commodious exterior cages into which the animals can pass whenever the weather is

suitable. Water is provided for each of these, and shade trees, suitably protected, have been planted in them, so that it is believed that they will add greatly to the comfort of the animals. Another very important improvement in this house has been effected by repairing the roof of the extension and rearranging the heating apparatus so as to adequately warm it. Although more habitable than before, it is not yet by any means a satisfactory building for tender animals, and it is hoped that this extension may at no distant day be rebuilt of stone, so as to correspond with the remainder of the house.

Perhaps the most urgent need of the park at the present time is the erection of buildings in which animals requiring varied conditions of exposure can be properly treated. At present there are practically but two conditions provided, those for animals that live out of doors during the entire winter and those of animals that require heat but are able to endure considerable changes of temperature. There is no provision for animals that live in close tropical climates where the heat varies but little.

Birds and monkeys and other animals from the valleys of the Amazon and the Orinoco find rapid changes very unfavorable. Besides this, it is impossible to give proper attention to the natural habits and idiosyncrasies of animals when they are kept promiscuously within a single inclosure. Timid animals suffer greatly when put in a house with large carnivorous beasts. The sight of such animals terrifies them and the cries of creatures whom they instinctively recognize as their natural enemies sometimes affects them so that they die from fright. A new building for monkeys and birds and a new elephant house are greatly needed.

The quarters for hardy animals are not in every respect what they should be. The principal defect is in the bear yards and dens in the abandoned quarry, near the main entrance to the park. These are too damp in winter and too hot in summer for the health of the animals, and are really unsuitable for them. One of the cages has become dangerous, because of the falling into it of large masses of rock. While they are picturesque and striking, much better quarters could be devised for the animals in other parts of the park. Upon some heavily wooded and cool slope an inclosure of considerable size could be made, so that they could be constantly upon the natural ground. Dry shelters could be provided either in hollow trees or by adapting crevices of rocks. In such a yard a considerable number of bears could be placed under conditions very similar to those of their native wilds. If care were taken to select young animals that were properly tamed before being placed in the inclosure, they would never have any fear of the public and would form an attractive exhibit.

The buffalo yards should be much larger than at present. As the animals destroy every green thing within reach, their paddocks soon present a very bare and forlorn appearance. This could be partially avoided by having two sets of paddocks, one of which could be occupied while the other was being allowed to recover from hard usage. If the paddocks were larger, there would be less danger of the animals injuring each other in their frequent conflicts. The largest bull of the herd was killed during the year by the attack of one of the smaller ones, who determined to contest his supremacy, and the small size of the inclosure prevented him from getting away from his antagonist.

The need of a proper public comfort house at the park is even more pressing each year as the number of visitors increases.

Some deaths of animals have occurred from accidental causes. A fine sea-lioness was killed by the accidental explosion of a large quantity of dynamite near the pond when she was swimming. This dynamite was to be used by the workmen employed in excavating for the intercepting sewer that passes through the park. The shock of the explosion was heard all over the city. The sea-lioness was not immediately killed, but died within twenty-four hours of the occurrence.

The beavers of the park are kept in two inclosures, and in both of these have built themselves dams and shelters. It is found, however, that care must be taken to

Rustic Bridge in Zoological Park.

select them from a single family, as otherwise they fight viciously. Four beavers died during the year from wounds received from their companions. The fence of the larger inclosure must be made much stronger, as it is found that they gnaw through an ordinary wire mesh-work.

There are appended hereto tables showing the animals in the collection at the close of the fiscal year, and the various accessions during the year.

Animals in the collection June 30, 1896.

Name.	No.	Name.	No.
MAMMALS.		MAMMALS—continued.	
American bison (*Bison americanus*)	6	Rhesus monkey (*Macacus rhesus*)	9
Zebu (*Bos indicus*)	3	White-throated capuchin (*Cebus hypoleucus*)	1
Common goat (*Capra hircus*)	5	Black-faced spider monkey (*Ateles ater*)	1
Cashmere goat (*Capra hircus*)	2	Owl monkey (*Nyctipithecus trivirgatus*)	2
American elk (*Cervus canadensis*)	13	Albino rat (*Mus rattus*)	18
Virginia deer (*Cariacus virginianus*)	18	American beaver (*Castor fiber*)	5
Mule deer (*Cariacus macrotis*)	2	Woodchuck (*Arctomys monax*)	4
Solid-hoofed hog (*Sus scrofa*, var. *solidungulata*)	1	Prairie dog (*Cynomys ludovicianus*)	25
Peccary (*Dicotyles tajaçu*)	3	Red-bellied squirrel (*Sciurus aureogaster*)	1
Llama (*Auchenia glama*)	8	Fox squirrel (*Sciurus niger*)	1
Guanaco (*Auchenia huanacos*)	1	Gray squirrel (*Sciurus carolinensis*)	18
Indian elephant (*Elephas indicus*)	2	Crested porcupine (*Hystrix cristata*)	4
Lion (*Felis leo*)	5	Canada porcupine (*Erethizon dorsatus*)	4
Tiger (*Felis tigris*)	1	Western porcupine (*Erethizon dorsatus epixanthus*)	1
Leopard (*Felis pardus*)	1	Capybara (*Hydrochœrus capybara*)	1
Puma (*Felis concolor*)	7	Crested agouti (*Dasyprocta cristata*)	3
Ocelot (*Felis pardalis*)	1	Hairy-rumped agouti (*Dasyprocta prymnolopha*)	2
Bay lynx (*Lynx rufus*)	1	Mexican agouti (*Dasyprocta mexicana*)	2
Spotted lynx (*Lynx rufus maculatus*)	5	Guinea pig (*Cavia porcellus*)	16
Spotted hyena (*Hyæna crocuta*)	3	English rabbit (*Lepus cuniculus*)	8
Russian wolf hound	2	Peba armadillo (*Tatusia novemcincta*)	10
Stag hound	1	Gray kangaroo (*Macropus* sp)	3
St. Bernard dog	2	Common opossum (*Didelphys virginiana*)	2
Pointer dog	2		
Collie dog	4	BIRDS.	
Chesapeake Bay dog	2		
Fox terrier	4	Golden eagle (*Aquila chrysaëtos*)	2
Eskimo dog	24	Bald eagle (*Haliæetus leucocephalus*)	9
Gray wolf (*Canis lupus griseo-albus*)	3	Red-tailed hawk (*Buteo borealis*)	1
Black wolf (*Canis lupus griseo-albus*)	2	Red-shouldered hawk (*Buteo lineatus*)	1
Coyote (*Canis latrans*)	4	Turkey vulture (*Cathartes aura*)	1
Red fox (*Vulpes fulvus*)	2	Great horned owl (*Bubo virginianus*)	2
Swift fox (*Vulpes velox*)	6	Barred owl (*Syrnium nebulosum*)	7
Gray fox (*Vulpes virginianus*)	1	Screech owl (*Megascops asio*)	1
Tayra (*Galictis barbara*)	1	Yellow and blue macaw (*Ara ararauna*)	1
American badger (*Taxidea americana*)	4	Red and yellow and blue macaw (*Ara macao*)	1
Kinkajou (*Cercoleptes caudivolvulus*)	1	Gray parrot (*Psittacus erithacus*)	6
Gray coati-mundi (*Nasua narica*)	2	Yellow-naped amazon (*Amazona auropalliata*)	1
Cacomistle (*Bassaris astuta*)	1	Green parrakeet (*Conurus* sp.)	1
Raccoon (*Procyon lotor*)	25	Sulphur-crested cockatoo (*Cacatua galerita*)	1
Black bear (*Ursus americanus*)	4	Leadbeater's cockatoo (*Cacatua leadbeateri*)	1
Cinnamon bear (*Ursus americanus*)	2	Bare-eyed cockatoo (*Cacatua gymnopis*)	1
Grizzly bear (*Ursus horribilis*)	2		
Macaque monkey (*Macacus cynomolgus*)	3		

Animals in the collection June 30, 1896—Continued.

Name.	No.	Name.	No.
BIRDS—continued.		BIRDS—continued.	
Common crow (*Corvus americanus*)	2	European white pelican (*Pelecanus onocrotalus*)	1
Raven (*Corvus corax*)	1	American herring gull (*Larus argentatus smithsonianus*)	1
Clarke's nutcracker (*Picicorvus columbianus*)	15	REPTILES.	
Black-headed jay (*Cyanocitta stelleri annectens*)	1	Alligator (*Alligator mississippiensis*)	15
American magpie (*Pica pica hudsonica*)	3	Snapping turtle (*Chelydra serpentina*)	2
Chachalaca (*Ortalis vetula maccallii*)	7	Painted turtle (*Chrysemys picta*)	6
Razor-billed curassow (*Mitua tuberosa*)	1	Musk turtle (*Cinosternum pennsylvanicum*)	2
Lesser razor-billed curassow (*Mitua tomentosa*)	1	Terrapin (*Pseudemys* sp.)	1
Peafowl (*Pavo cristatus*)	10	Gopher turtle (*Xerobates polyphemus*)	2
Guinea fowl (*Numida meleagris*)	2	Gila monster (*Heloderma suspectum*)	3
Domestic turkey (*Meleagris gallopavo*)	1	Horned lizard (*Phrynosoma cornutum*)	26
Cariama (*Cariama cristata*)	1	Diamond rattlesnake (*Crotalus adamanteus*)	3
Sand-hill crane (*Grus canadensis*)	1	Prairie rattlesnake (*Crotalus confluentis*)	1
Great blue heron (*Ardea herodias*)	2	Copperhead (*Ancistrodon contortrix*)	3
Wood ibis (*Tantalus loculator*)	1	Water moccasin (*Ancistrodon piscivorus*)	2
Black duck (*Anas obscura*)	5	Boa (*Boa constrictor*)	3
Pekin duck (*Anas* sp.)	11	Anaconda (*Eunectes murinus*)	1
Canada goose (*Branta canadensis*)	4	Bull snake (*Pituophis sayi*)	1
Chinese goose (*Anser cygnoides*)	8	Milk snake (*Ophibolus doliatus*)	1
Toulouse goose (*Anser* sp.)	2	Black snake (*Bascanium constrictor*)	8
Mute swan (*Cygnus gibbus*)	6	Garter snake (*Eutænia sirtalis*)	2
Whistling swan (*Cygnus columbianus*)	1	Water snake (*Natrix sipedon*)	12
Black swan (*Chenopis atrata*)	1		

	Indigenous.	Foreign.	Domesticated.	Total.
Mammals	185	46	102	333
Birds	68	18	40	126
Reptiles	90	4		94
Total	343	68	142	553

List of accessions.

ANIMALS PRESENTED.

Name.	Donor.	Number of specimens.
Rhesus monkey	Dr. J. J. Kinyoun, U. S. Marine Hospital, Washington, D. C	1
White-throated cebus	do	1
Capuchin monkey	do	1
Puma	Geo. H. Tice, Monero, N. Mex	2
Chesapeake Bay dog	B. Alton Smith, North Attleboro, Mass	2
Collie	do	1
Eskimo dog	Lieut. R. E. Peary, U. S. N	4
Fox terrier	John E. Thayer, Lancaster, Mass	2
Do	Dr. H. M. Perry, Greenville, S. C	1
Old English sheep dog	do	1

Rockwork in Zoological Park.

List of accessions—Continued.

ANIMALS PRESENTED—Continued.

Name.	Donor.	Number of specimens.
Pointer dog	Jas. C. Courts, Washington, D. C	1
St. Bernard dog	J. H. King, Alexandria, Va	1
Staghound	R. E. Earll, Washington, D. C	1
Wire-haired fox terrier	Dr. H. T. Foote, New Rochelle, N. Y	1
Red fox	Dr. Pearson, Washington, D. C	2
Swift fox	S. H. Stephens & Co., Pueblo, Colo	3
Gray fox	Dr. W. F. Hutchinson, Winchester, Va	1
American badger	H. T. McGeorge, Fort Myer Heights, Va	1
Raccoon	C. Moore, Rest, Va	3
Do	Mrs. H. M. Frinald, Washington, D. C	1
Harbor seal	John H. Starin, New York, N. Y	1
Solid-hoofed hog	A. B. Walker, Indian Territory	1
Canada porcupine	Gerald Thayer, Dublin, N. H	5
English rabbit	F. Wright, Mount Pleasant, D. C	6
Do	Jos. Stewart, Washington, D. C	1
Peba armadillo	Edw. S. Schmid, Washington, D. C	1
Opossum	Miss Rene Vose, Washington, D. C	1
Turkey vulture	Edw. S. Schmid, Washington, D. C.	1
Golden eagle	J. W. Pattison, Wytheville, Va	2
Bald eagle	McTill Belt, Dickerson, Md	2
Red-tailed hawk	J. L. Davison, Lockport, N. Y	1
Great horned owl	F. W. Bradley and D. C. Cone, Riverton, Va	1
Do	Camm Brothers, Lynchburg, Va	1
Barred owl	Mrs. Berry, Washington, D. C	1
Do	D. C. Turner, Lanier Heights, D. C	1
Do	C. B. Arundell, Farmwell, Va	3
Screech owl	Mrs. H. M. Frinald, Washington, D. C	1
Gray parrot	Miss Rachel Weems, Upper Falls, Md	5
Blue-fronted amazon	J. W. Bartley, Anacostia, D. C	1
Clarke's nutcracker	Eugene Pence, Columbia Falls, Mont	11
African ostrich	W. A. Smith, Whitneys Point, N. Y	1
Whistling swan	E. E. Fast, Johnstown, Nebr	1
Black skimmer	Wm. Palmer, Washington, D. C	2
Alligator	Dennis Lynch, Washington, D. C	2
Do	W. W. Rickett, Washington, D. C	1
Do	Mrs. W. E. Parker, Washington, D. C	2
Tortoise	G. K. Gilbert, Pueblo, Colo	2
Iguana	Ralston Brothers, Galesburg, Ill	1
Horned lizard	Lyman J. Bailey, Austin, Texas	26
Diamond rattlesnake	Ralston Brothers, Galesburg, Ill	1
Do	Jas. Bell, Gainesville, Fla	2
Prairie ratttlesnake	L. W. Purinton, Banner, Kans	3
Water moccasin	Ralston Bros., Galesburg, Ill	2
Bull snake	do	1
Black snake	Jas. P. Stabler, Sandyspring, Md	1
Do	Jas. W. Magarity, Lewinsville, Va	1
Do	J. E. Taylor, Baltimore, Md	1
Garter snake	W. B. K. Johnson, Allentown, Pa	1
Milk snake	Chas. Long, Washington, D. C	1

List of accessions—Continued.

ANIMALS LENT.

Name.	Donor.	Number of specimens.
Macaque monkey	Edw. S. Schmid, Washington, D. C.	1
Rhesus monkey	Dr. J. J. Kinyoun, U. S. Marine Hospital, Washington, D. C.	3
Do	Edw. S. Schmid, Washington, D. C	10
Black-faced spider monkey	Mrs. J. L. Waggaman, Washington, D. C	2
Eskimo dog	Miner W. Bruce, Seattle, Wash	2
Cashmere goat	C. O. Chenault, New Orleans, La	2
Virginia deer	W. A. Smith, Whitneys Point, N. Y	2
Fox squirrel	C. O. Chenault, New Orleans, La	1
Peba armadillo	Edw. S. Schmid, Washington, D. C	9
Golden eagle	do	1
Bald eagle	H. T. L. Hoyle, Washington, D. C	3
Barred owl	E. J. Court, Washington, D. C	2
Yellow and blue macaw	Edw. S. Schmid, Washington, D. C	1
Yellow-naped amazon	Mrs. A. B. Williams, Washington, D. C	1
Green parrakeet	K. P. McElroy, Washington, D. C	1
Peafowl	C. O. Chenault, New Orleans, La	2
Mongolian pheasant	Hon. F. T. Dubois, Blackfoot, Idaho	2
Guinea fowl	C. O. Chenault, New Orleans, La	2
Whistling swan	Edw. S. Schmid, Washington, D. C	1
African ostrich	W. A. Smith, Whitneys Point, N. Y	1
King snake	R. G. Paine, Washington, D. C	2

ANIMALS RECEIVED IN EXCHANGE.

Name.	From.	Number of specimens.
Diana monkey	Edw. S. Schmid, Washington, D. C	1
Red fox	do	2
Raccoon	do	5
Black bear	do	1
Virginia deer	Commission of parks and boulevards, Detroit, Mich	5
Do	Thos. Blagden, Argyle, D. C	1
Chinese goose	Edw. S. Schmid, Washington, D. C	3
Toulouse goose	do	2
Prairie rattlesnake	Ralston Brothers, Galesburg, Ill	1
Bull snake	do	1

Animals born in the National Zoological Park.

Lion (*Felis leo*)	4
Puma (*Felis concolor*)	5
Spotted lynx (*Lynx rufus maculatus*)	2
Eskimo dog	12
St. Bernard dog	4
Raccoon (*Procyon lotor*)	6
American elk (*Cervus canadensis*)	1
Virginia deer (*Cariacus virginianus*)	6
Llama (*Auchenia glama*)	2
Canada porcupine (*Erethizon dorsatus*)	1

Young Elk in Zoological Park.

Guinea pig (*Cavia porcellus*)	6
English rabbit (*Lepus cuniculus*)	7
Gray kangaroo (*Macropus* sp.)	2
European swan (*Cygnus gibbus*)	4
Prairie rattlesnake (*Crotalus confluentis*)	6

Animals collected in the Yellowstone National Park.

Bald eagle (*Haliætus leucocephalus*)	3
Red-tailed hawk (*Buteo borealis*)	2
Magpie (*Pica pica hudsonica*)	10
Clarke's nutcracker (*Picicorvus columbianus*)	3

SUMMARY OF ACCESSIONS.

Animals presented		130
Animals lent		51
Animals received in exchange		22
Animals born in the Zoological Park		68
Animals received from the Yellowstone National Park		18
Total		289
Number of specimens on hand June 30, 1895		520
Accessions during the year ending June 30, 1896		289
Total		809
Deduct—		
Deaths	200	
Animals escaped or liberated	13	
Animals exchanged	21	
Animals returned to owners	22	
		256
Animals on hand June 30, 1896		553

Respectfully submitted.

FRANK BAKER, *Superintendent.*

Mr. S. P. LANGLEY,

Secretary of the Smithsonian Institution.

APPENDIX V.

REPORT ON THE WORK OF THE ASTROPHYSICAL OBSERVATORY FOR THE YEAR ENDING JUNE 30, 1896.

SIR: The bolometric investigation of the infra-red solar spectrum has, under your general direction, continued to be the main feature of the work of the Observatory for the past year. While it has been found necessary to postpone a final account of the result of this long investigation, yet it is confidently believed that such a publication can be made before many months more; and that the limit of accuracy in determining the position of absorption lines, which was mentioned in the report for the last year as the aim of endeavor, will be reached in the results shortly to be communicated.

The year's prosecution of the research will, for convenience, be discussed under the following heads:

A. Measurement and elimination of "the drift"[1] and other sources of error in the spectrobolo-metric processes.

B. General spectrobolographic work.

C. Accessions of apparatus.

A. MEASUREMENT AND ELIMINATION OF SOURCES OF ERROR IN THE SPECTROBOLOMETRIC PROCESSES.

As detailed in the report for the year ending June 30, 1895, it was then evident that the bolographic curves were so encumbered with minute deflections due to earth vibrations and extraneous electrical and magnetic disturbances, that the small and, it was presumed, very numerous deflections corresponding to fine absorption lines were greatly obscured. One of the means proposed for eliminating false and retaining true lines has been the process of composite photography. The method of application of this process had been as follows: 1. All the deflections in a series of curves of a greater magnitude than a certain arbitrary amount were by the "cylindric process" drawn out into lines. 2. The resulting "cylindrics" were successtvely exposed before a single plate to give a composite.

It must be remarked the process of experiment has shown that this procedure is not free from objection. While it is unquestionable that deflections great enough to be surely recognized as genuine will be brought out, owing to the greater prominence given them in "blocking in" the curves preparatory to making the "cylindrics," yet many of the genuine deflections of the same size as the accidental ones (for distinguishing which the process is chiefly useful) may possibly be eliminated; for owing to the various sources of error in the bolometric processes, particularly the superposition of accidental deflections over the true ones, to the personal error in blocking in, and to the errors introduced in the photographic processes, slight lateral displacements of the true lines in the separate cylindrics will always occur. Thus it may frequently happen that in the final composite the less prominent lines, being thus variable in their position to an amount equal to their own width, or even more, may be eliminated. Lines corresponding to accidental deflections may, on the other hand, be retained, since their number is very great in comparison with the number of cylindrics employed in making composites, for it may thus frequently happen

[1] It will be remembered that "the drift" has hitherto been a principal source of trouble in these researches. It consists in a slow progressive movement of the needle due to a great variety of extraneous causes.

that there will be sufficiently close correspondence between such false lines in all the cylindrics employed, so that they will appear in the final composite.

Of late another method of combining the results to be derived from the separate curves has come into use at the observatory, which is briefly as follows:

1. Each of the several observers independently superposes the set of curves under investigation, and from the general appearance and size of the deflections selects those which he considers to probably correspond to genuine absorption bands, and marks them relatively to their importance and to the evidence of their genuineness.

2. He then measures upon the comparator the positions of his selected deflections on each curve separately without sight of the others.

3. The results thus obtained are averaged, throwing out such deflections as appear from the divergence of the measurements to be accidental.

4. The mean results of the separate observers are compared and reduced, indicating the extent to which the observers agree with regard to the importance and verity of the different deflections.

In view of the limitations of the composite process, it is proposed that it be kept subordinate to that just described, and only used in the preparation of a spectrum map in which the exact place of each line appearing shall be independently determined.

The multiplicity and injurious character of the accidental deflections continued painfully evident throughout the bolographic harvest season of the year (the months of September, October, and November). Fine days were also frequently lost after cold weather came on, owing to the rapid "drift" of the galvanometer needle, caused by the changing temperature conditions incident to the warming of the observatory.

In these circumstances the work of taking bolographs was suspended for some months, and the following important improvements were, after many experiments, adopted, which have separately and in concert been signally successful in reducing these sources of error:

1. In extension of the principle introduced at Allegheny, a battery of sixty storage cells connected in parallel replaced the four cells formerly employed, and effected great reduction of small accidental deflections of the galvanometer needle.

2. A specially constructed rheostat, entirely surrounded by a water jacket and provided with a slide wire adjustment operated mechanically from without, replaced the resistance box before used to balance the bolometer strips. In this instrument only a single pair of coils of the same resistance as the particular bolometer employed is used. The number of contacts between dissimilar metals is reduced to a minimum, and all are kept from fluctuations of temperature by a continuous current of water.

3. The galvanometer, formerly supported upon a system of flat stones and rubber, has been suspended by three wires from a tripod, after the manner of Julius.[1] This method of support is found to decidedly reduce the vibrations of the galvanometer needle due to ground tremors.

4. The double-walled room which surrounds the spectrometer has been extended to include the galvanometer also; and thus temperature fluctuations about the galvanometer control magnets have been reduced, to the great diminution of the "drift."

5. The whole observatory has been equipped with an automatic system of temperature regulation, and the heat is supplied both night and day from steam boilers in the basement of the Smithsonian main building. So successful has this system proved that during the cold months the whole fluctuations of temperature within the spectrometer room are reduced to little more than a tenth of a degree.

6. A new galvanometer needle has been constructed with a considerably higher degree of astaticism and somewhat greater sensitiveness than the one before in use.

As the result of the improvements mentioned above, the "drift," heretofore so

[1] Wiedemann's Annalen, *56*, 151.

vexatious, has been reduced to such a degree that its whole amount for a week's time often does not exceed 2 centimeters, or the amount which it had in the early experiments in a single minute. This result, it must be remembered, is reached with the galvanometer adjusted to such a sensitiveness that a millimeter deflection on the scale corresponds to six ten-billionths of an ampère in the galvanometer circuit. Not only is the drift thus practically eliminated, but the small deflections from accidental causes which heretofore so obscured the deflections corresponding to real absorption lines, while still very numerous, are now reduced to an amplitude rarely exceeding two-tenths of a millimeter. Occasional deflections of a little greater magnitude occur, but not often, and these can be readily eliminated in a comparison of curves. The deflections now remaining are almost wholly due to ground tremors not entirely eliminated by the system of suspension of the galvanometer.

This large decrease of drift and incidental deflections brought out the defects in the construction of most bolometers hitherto in use, and on analysis it was found that the enhanced "drift" when these were employed was due to the hard rubber insulation, and that small accidental deflections were caused by imperfect fastening of the strips at the ends. A bolometer frame of metal with mica insulation was filled at the observatory and has proved very satisfactory.

Another source of drift not before noticed was found to be the falling of the spectrum upon the bolometer case during a run from A to Ω, and it was entirely removed by a suitable diaphragm.

These observations on the drift and false deflections in the record may be suitably closed by the remark that under your instructions of March, 1896, it has been the invariable practice to make a short record curve, with no heat falling on the bolometer, both at the beginning and end of each bolograph, to show the instrumental conditions prevailing. Such records were occasionally taken in former years, and were included in the report of the number of bolographs taken. So many have this year been taken, however, that it seemed misleading to include them in the count, and they are accordingly entirely neglected in the table of photographs given below, and only those curves which represent some part of the spectrum are there counted as bolographs.

After the approach of hot weather rendered it impossible to continue uniform temperature conditions, the work of taking bolographs was again discontinued, and extensive quantitative experiments were prosecuted to determine the magnitude of the probable error arising from the many sources attendant upon the complicated bolometric process. The results of these experiments revealed in several instances greater error than was suspected, and led to important changes in the apparatus which are not at the close of the period covered by this report entirely completed.

A detailed account of the methods employed in determining the various sources of error must be postponed till the appearance of the forthcoming publication; but it will be proper in this place to give a brief summary of the investigations.

Laying down as in the report for last year ending June 30, 1895, an accuracy of one-tenth millimeter in position of a deflection upon the bolographic curve (corresponding under the convention of speeds adopted to six-tenths second of arc in the spectrum, or to three-tenths second of arc on the circle) as the limit of accuracy desired in the final results, this amount of error will be treated as in a sense the unit of error in this discussion:

I. *Sources of error in the optical apparatus.*

1. Apparent displacements of the slit—
   a. Momentary, from ground tremors and from air currents of different density Displacements now negligible, as a result of recent improvements.
   b. Periodic, from temperature and other changes in the supports of optical apparatus. Important errors from this cause were within the last month covered by this report eliminated.

2. Imperfect adjustment of the prism-mirror combination for minimum deviation—
   Errors from this cause proved negligible under the assumption of parallel rays. As steps are now being taken to introduce a system of collimation for the beam with a view to improve the definition of the optical system, further discussion for a divergent beam is unnecessary.
3. Changes in the temperature of the prism—
   No new data on the change of deviation with the temperature have been obtained, but referring to those of a preliminary nature contained in your paper on the "Temperature of the Moon,"[1] it is believed that errors from this source in curves taken under usual conditions will not exceed 2 seconds of an arc in deviation. With the attainment of accurate data such errors may be corrected.

II. *Sources of error which introduce accidental deflections in the record curves.*

1. Disturbances primarily affecting the galvanometer needle including (*a*) earth tremors; (*b*) magnetic disturbances.
2. Disturbances secondarily affecting the galvanometer needle through the bolometer circuit including (*a*) those causing "drift;" (*b*) those causing "flutter" in the records.
   The whole effect of these four classes of disturbances as shown by the record curves already mentioned will be, under usually good conditions, to displace true deflections on an average about one-tenth millimeter on the plate. All true deflections of a magnitude not greater than two-tenths millimeter are lost among the false ones.

III. *Sources of error from imperfect mechanisms.*

1. Irregularities in the motion of the plate.
   Errors from this source negligible.
2. Irregularities in the motion of the circle.
   Errors now occasionally as great as 3 seconds of arc; but steps being now taken which promise to reduce these irregularities to a magnitude of five-tenths second.
3. Difficulty in correctly determining the ratio of plate and circle motions.
   A more accurate method of determination now projected will undoubtedly give sufficient accuracy.

IV. *Sources of error in preparing cylindrics.*

1. Personal error in "blocking in."
   Experiments show that the mean displacements of lines from this cause vary with three persons from 0.16 to 0.32 millimeter.
2. Imperfect adjustments of camera.
   As a result of recent changes the error from this cause will not exceed one-tenth millimeter in the length of a 20-centimeter plate, and is within certain limits proportional to the length of the plate employed.

V. *Errors in comparator measurements.*

1. Personal error in the determination of a minimum upon the curves.
   Experiments show that the average deviations of the mean of two observations by one observer from the mean result of six observations on the same curve by three observers varies with different persons from 0.022 to 0.016 millimeter.
2. Errors peculiar to the comparator.
   A new comparator is projected for use in the observatory in which it is believed these errors will be negligible.

[1] S. P. Langley, "Temperature of the Moon." Memoirs of the National Academy of Science, Volume IV, 9, Appendix 3.

VI. *Sources of error inherent in the bolometric method.*

1. From tardy action of the galvanometer, due to electrostatic causes, damping of the needle, etc., causing displacement of deflections.

   May be eliminated by reversing the direction of motion of the circle between different runs, as has already been pointed out, and heretofore practiced.

As a general summing up of these investigations it may be said that if the steps now being taken are successful in their outcome, it will be possible to determine the difference of deviation between the lines appearing on the bolographs and the A line in the visible spectrum, with an error not exceeding 1 second of arc.

The number of lines which may be theoretically discriminated with the process and apparatus employed is very large. With a perfect prism of the size used, and a galvanometer of somewhat greater sensitiveness, more than a thousand might, if they exist, be discovered within the region in which we are now working. But this supposes all minor tremors in the bolographic curves to be eliminated, and it is certain that this has not yet been done, and that very many of the lines shown in maps exhibited in illustration of the process will prove to have been due to such causes. The chief aim at the present stage of the investigation is to give a number of lines with their positions in the spectrum of a 60° rock salt prism, which may be regarded as "standards," and as many more as may be considered to have been verified beyond reasonable doubt. Of these it is believed that at least 200 can be presented in the forthcoming publication.

B. General Spectrobolographic Work.

In the following table is given the number of photographs of various kinds taken at the observatory during the year, not including instrumental records taken to show the magnitude of the accidental galvanometer deflections:

Date.	Bolographs.	Cylindrics.	Other photographs.
1895.			
July	10	7	0
August	28	24	3
September	46	0	3
October	47	27	2
November	21	12	10
December	7	11	7
1896.			
January	0	6	0
February	2	0	3
March	38	2	3
April	10	1	15
May	0	6	11
June	0	0	0
Total	209	96	57

Grand total, 362.

Full comparator measurements on curves of April, 1894, and March, 1896, have been made by three observers after the manner already described, and the results have been reduced to deviation. The curves measured were taken with coarse bolometer at a rapid rate of speed, and the finer lines were thus eliminated. About 80 prominent or "standard" lines were verified in each of the sets of curves measured.

It has been repeatedly remarked in these reports that the most satisfactory results can not be obtained in the site at present occupied by the observatory within the

city, subject to all sorts of ground and electric tremors, when the elimination of these tremors is so vitally necessary to success. While the effects, due to vibration, have been greatly reduced by means already alluded to, yet they still exist. It may be incidentally observed that experiment has shown that these small ground tremors are only about one-third as great at night as in the day, a condition owing to the difference in the amount of traffic in the neighboring streets. Experiments were also to be made to compare the magnetic disturbances due to electrical causes with those at the magnetic station at the United States Naval Observatory without the city, but only a small difference in favor of the latter site was found. Induction effects in the bolometer circuit might have been expected to be caused by electric currents in neighboring street lines; but owing to the special winding of the coils and careful arrangement of all connections this disturbance has been much smaller than has been anticipated. When all is said, however, it unfortunately remains true that the best results can never be reached in the present situation.

C. Accessions of Apparatus.

The principal accessions of apparatus during the past year are as follows:

1. A 6-inch telescope with photographic and visual objectives, 4 eyepieces, 2 amplifying lenses, and spectroscopic attachment.
2. Special camera for exposing the moving plate in making bolographs.
3. A slit with 12-centimeter jaws for use in place of cylindric lens in producing linear translations of bolographs.
4. Special rheostat with slide wire all inclosed by water jacket for use in the bolometer circuit.
5. Great battery of 60 storage cells for the bolometer circuit, with appropriate switch for charging and discharging.
6. Temperature controlling apparatus.
7. A new governor for the siderostat.
8. Stereoscopic camera.
9. Telephoto camera.
10. Projection lantern with accessories.

PERSONNEL.

Mr. C. G. Abbot succeeded Mr. R. C. Child as aid acting in charge, January 1, 1896. Mr. R. C. Child left the observatory June 30, 1896. Mr. L. E. Emerson was appointed as assistant on June 26, 1896.

I may sum up the results of the last year's work in saying that an entirely new stage of accuracy has been reached by the elimination of sources of error of long standing, and that as a result of this accuracy between 200 and 300 well-determined lines may be expected to appear in a communication which it is expected in the next year to publish.

Respectfully submitted.

C. G. Abbot,
Aid Acting in Charge, Astrophysical Observatory.

Mr. S. P. Langley,
Secretary of the Smithsonian Institution.

Appendix VI.

REPORT OF THE LIBRARIAN FOR THE YEAR ENDING JUNE 30, 1896.

Sir: I have the honor to present herewith a report upon the operations of the library of the Smithsonian Institution during the fiscal year ended June 30, 1896.

The entry numbers of accessions to the Smithsonian deposit at the Library of Congress extend from 314,500 to 339,339.

The following table gives an analysis in volumes, parts of volumes, pamphlets, and charts of the accessions during the year:

Publications received between July 1, 1895, and June 30, 1896.

	Quarto or larger.	Octavo or smaller.	Total.
Volumes	330	1,350	1,680
Parts of volumes	17,504	8,923	26,427
Pamphlets	558	3,692	4,250
Charts			236
Total			32,583

In addition to this there have been added to the Secretary's library, office library, and the library of the Astrophysical Observatory 276 volumes and pamphlets, and 2,061 parts of volumes, making a total of 2,337, and a grand total of accessions for the year of 34,920 volumes, parts of volumes, pamphlets, and charts.

These accessions show a gain of 2,967 in volumes and parts of volumes over the previous year; and in the number of entries, 3,366.

Of these accessions 333 volumes, 759 parts of volumes and periodicals, and 1,047 pamphlets were retained for the use of the United States National Museum, and 993 medical dissertations were deposited in the library of the Surgeon-General, United States Army, the remaining publications being sent to the Library of Congress on the Monday after their receipt.

The names on the lists, procured in accordance with the plan of the Secretary formulated in 1887, for increasing the library by exchanges, having been exhausted the Secretary directed that this work for the present be continued by entering into correspondence with all publishing societies on the new lists of the Bureau of Exchanges, whose publications were not already being received by the Library. In pursuance of this direction 732 letters were written asking for the publications which were not on the list or for numbers to complete the series already in the Library, with the gratifying result that 249 new exchanges were entered into and that 155 defective series were either completed or added to as far as the publishers could supply the missing parts.

The following universities have sent complete sets of their academic publications, including inaugural dissertations:

Basel,
Berlin,
Bern,
Bonn,
Breslau,
Chicago,
Columbia,
Cornell,
Dorpat,
Erlangen,
Freiberg,
Giessen,
Griefswald,
Halle,
Heidelberg,
Helsingfors,
Jena,
Johns Hopkins,
Kiel,
Königsberg,
Leipzig,
Louvain,
Lund,
Marburg,
Michigan,
Minnesota,
Pennsylvania,
Strassburg,
Tubingen,
Utrecht,
Wurzburg,
Zurich.

Respectfully submitted.

Cyrus Adler, *Librarian.*

Mr. S. P. Langley,

Secretary of the Smithsonian Institution.

APPENDIX VII.

REPORT OF THE EDITOR FOR THE YEAR ENDING JUNE 30, 1896.

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution for the year ending June 30, 1896:

I. SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

The first memoir of the Contributions to Knowledge was by Messrs. Squier and Davis on Ancient Monuments of the Mississippi Valley, published in 1848. Thirty quarto volumes and parts of two additional volumes have since been published, comprising 129 memoirs pertaining to nearly every branch of knowledge.

Volumes XXX, XXXI, and XXXII were completed during this year, the first two being the text and plates of an exhaustive treatise on Oceanic Ichthyology by Dr. G. Brown Goode and Dr. Tarleton H. Bean, and the last volume a second contribution by Major Bendire on the Life Histories of North American Birds.

No. 980. On the Densities of Oxygen and Hydrogen, and on the Ratio of their Atomic Weights, by Edward W. Morley, Ph. D. (Part of Vol. XXIX of Smithsonian Contributions to Knowledge.) Octavo pamphlet of 128 pages, illustrated with 40 text figures.

Nos. 981, 982. Oceanic Ichthyology, a Treatise on the Deep-Sea and Pelagic Fishes of the World, by George Brown Goode and Tarleton H. Bean. Two quarto volumes, text xxxv (26), 553 pages, and an atlas of 417 figures on 123 plates. (Vols. XXX and XXXI of Smithsonian Contributions to Knowledge.)

Nos. 983, 984. Volumes XXX and XXXI of Contributions, as above.

No. 985. Life Histories of North American Birds, from the Parrots to the Grackles, with special reference to their breeding habits and eggs. By Maj. Charles Bendire, United States Army. Quarto volume of viii, 518 pages, illustrated with seven lithographic plates. (Vol. XXXII of Smithsonian Contributions to Knowledge.)

No. 986. Volume XXXII, Smithsonian Contributions to Knowledge, as above.

No. 989. The Composition of Expired Air and its Effects upon Animal Life, by Drs. J. S. Billings, S. Weir Mitchell, and D. H. Bergey. (Part of Vol. XXIX of Smithsonian Contributions to Knowledge.) Octavo pamphlet of 84 pages.

II. SMITHSONIAN MISCELLANEOUS COLLECTIONS.

The first volume of the Miscellaneous Collections was published in 1862, and the series now numbers 35 completed octavo volumes, embracing 167 distinct papers, besides parts of 4 additional volumes.

The following papers of this series were published during the past fiscal year:

No. 1031. An Index to the Genera and Species of the Foraminifera, by Charles Davies Sherborn. Part II, Non to Z. (Part of Vol. XXXVII of Smithsonian Miscellaneous Collections.) Octavo pamphlet of 248 pages. Part I of this work was published in 1894.

No. 1032. Smithsonian Meteorological Tables. Revised edition. Octavo pamphlet of 333 pages. This revised edition contains an index and the "International Meteorological Symbols" not included in the first edition, published in 1893. (Part of Vol. XXXV of Smithsonian Miscellaneous Collections. The other parts of this volume are Geographical Tables, published in 1894, and the Physical Tables, now in press.)

III. PAPERS FROM ANNUAL REPORT.

No. 990. Report of S. P. Langley, Secretary of the Smithsonian Institution, for the year ending June 30, 1895. An octavo pamphlet of 86 pages, with 6 full-page illustrations.

No. 993. Proceedings of Regents. Report of executive committee. Acts of Congress. (From the Smithsonian Report for 1894.) Octavo pamphlet of 30 pages.

No. 994. On the Magnitude of the Solar System, by William Harkness. (From the Smithsonian Report for 1894.) Octavo pamphlet of 28 pages.

No. 995. Schiaparelli's Latest Views Regarding Mars, by William H. Pickering. (From the Smithsonian Report for 1894.) Octavo pamphlet of 15 pages; illustrated with 1 plate.

No. 996. Light and Electricity, according to Maxwell and Hertz, by M. Poincaré. (From the Smithsonian Report for 1894.) Octavo pamphlet of 10 pages.

No. 997. The Henry, by T. C. Mendenhall. (From the Smithsonian Report for 1894.) Octavo pamphlet of 11 pages.

No. 998. The Age of Electricity, by M. Mascart. (From the Smithsonian Report for 1894.) Octavo pamphlet of 19 pages.

No. 999. Terrestrial Magnetism, by Prof. A. W. Rücker. (From the Smithsonian Report for 1894.) Octavo pamphlet of 16 pages.

No. 1000. Photographic Photometry, by M. J. Janssen. (From the Smithsonian Report for 1894.) Octavo pamphlet of 14 pages; illustrated with 15 plates.

No. 1002. The Waste and Conservation of Plant Food, by Harvey W. Wiley. (From the Smithsonian Report for 1894.) Octavo pamphlet of 22 pages.

No. 1003. Four Days' Observation at the Summit of Mont Blanc, by M. J. Janssen. (From the Smithsonian Report for 1894.) Octavo pamphlet of 10 pages.

No. 1004. Weather Making, Ancient and Modern, by Mark W. Harrington. (From the Smithsonian Report for 1894.) Octavo pamphlet of 21 pages.

No. 1005. Variation of Latitude, by J. K. Rees. (From the Smithsonian Report for 1894.) Octavo pamphlet of 8 pages.

No. 1006. The Development of the Cartography of America up to the Year 1570, by Dr. Sophus Ruge. (From the Smithsonian Report for 1894.) Octavo pamphlet of 15 pages; illustrated with 28 plates.

No. 1007. Antarctica: A Vanished Austral Land, by Henry O. Forbes. (From the Smithsonian Report for 1894.) Octavo pamphlet of 19 pages.

No. 1008. The Promotion of Further Discovery in the Arctic and Antarctic Regions, by Clements R. Markham. (From the Smithsonian Report for 1894.) Octavo pamphlet of 24 pages.

No. 1009. The Physical Condition of the Ocean, by Capt. W. J. L. Wharton, R. N. (From the Smithsonian Report for 1894.) Octavo pamphlet of 15 pages.

No. 1010. The Origin of the Oldest Fossils and the Discovery of the Bottom of the Ocean, by Prof. W. K. Brooks. (From the Smithsonian Report for 1894.) Octavo pamphlet of 17 pages.

No. 1011. The Relations of Physiology to Chemistry and Morphology, by Giulio Fano. (From the Smithsonian Report for 1894.) Octavo pamphlet of 12 pages.

No. 1012. The Work of the Physiological Station at Paris, by E. J. Marey. (From the Smithsonian Report for 1894.) Octavo pamphlet of 21 pages; illustrated with 8 plates.

No. 1013. The Method of Organic Evolution, by Alfred R. Wallace. (From the Smithsonian Report for 1894.) Octavo pamphlet of 22 pages.

No. 1014. The Part Played by Electricity in the Phenomena of Animal Life, by M. Ernest Solvay. (From the Smithsonian Report for 1894.) Octavo pamphlet of 13 pages.

No. 1015. The Influence of Certain Agents Destroying the Vitality of the Typhoid and of the Colon Bacillus, by John S. Billings and Adelaide Ward Peckham. (From the Smithsonian Report for 1894.) Octavo pamplet of 7 pages.

No. 1016. Modern Developments of Harvey's Work in the Treatment of Diseases of the Heart and Circulation, by Dr. T. Lauder Brunton, F. R. S. (From the Smithsonian Report for 1894.) Octavo pamphlet of 19 pages.

No. 1017. Ants' Nests, by Dr. August Forel. (From the Smithsonian Report for 1894.) Octavo pamphlet of 26 pages; illustrated with 2 plates.

No. 1018. The Evolution of Modern Society in its Historical Aspects, by R. D. Melville. (From the Smithsonian Report for 1894.) Octavo pamphlet of 14 pages.

No. 1019. Migration and the Food Quest. A Study in the Peopling of America, by Otis Tufton Mason. (From the Smithsonian Report for 1894.) Octavo pamphlet of 17 pages; illustrated with 1 plate.

No. 1020. The Guanches: The Ancient Inhabitants of Canary, by Capt. J. W. Gambier, R. N. (From the Smithsonian Report for 1894.) Octavo pamphlet of 12 pages; illustrated with 15 text figures.

No. 1021. Psychology of Prestidigitation, by Alfred Binet. (From the Smithsonian Report for 1894.) Octavo pamphlet of 16 pages.

No. 1022. A Discovery of Greek Horizontal Curves in the Maison Carrée at Nimes, by William Henry Goodyear. (From the Smithsonian Report for 1894.) Octavo pamphlet of 15 pages; illustrated with 6 plates.

No. 1023. The Methods of Archæological Research, by Sir Henry Howorth, F. R. S. (From the Smithsonian Report for 1894.) Octavo pamphlet of 19 pages.

No. 1024. The Art of Casting Bronze in Japan, by W. Gowland, F. S. A. (From the Smithsonian Report for 1894.) Octavo pamphlet of 42 pages; illustrated with 7 plates.

No. 1025. Study and Research, by Rudolph Virchow. (From the Smithsonian Report for 1894.) Octavo pamphlet of 13 pages.

No. 1026. Scientific Problems of the Future, by Lieut. Col. H. Elsdale. (From the Smithsonian Report for 1894.) Octavo pamphlet of 13 pages.

No. 1027. The Founding of the Berlin University and the Transition from the Philosophic to the Scientific Age, by Rudolph Virchow. (From the Smithsonian Report for 1894.) Octavo pamphlet of 15 pages.

No. 1028. The Institute of France in 1894, by M. Loewy, president of the Institute. (From the Smithsonian Report for 1894.) Octavo pamphlet of 12 pages.

No. 1029. Herman von Helmholtz, by Arthur W. Rücker, F. R. S. (From the Smithsonian Report for 1894.) Octavo pamphlet of 10 pages.

No. 1030. Sketch of Heinrich Hertz, by Helene Bonfort. (From the Smithsonian Report for 1894.) Octavo pamphlet of 8 pages.

IV. PUBLICATIONS OF BUREAU OF ETHNOLOGY.

The annual reports and bulletins of the Bureau of Ethnology published during the year are mentioned in the Director's report.

V. PUBLICATIONS OF NATIONAL MUSEUM.

The National Museum has issued several Bulletins and papers of the Proceedings, which are enumerated on another page.

Respectfully submitted.

A. HOWARD CLARK.

Mr. S. P. LANGLEY,

Secretary of the Smithsonian Institution.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1896.

ADVERTISEMENT.

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the Secretary, induced in part by the discontinuance of an annual summary of progress which for thirty years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report, for 1896.

THE PROBLEMS OF ASTRONOMY.[1]

By Prof. SIMON NEWCOMB.

Assembled, as we are, to dedicate a new institution to the promotion of our knowledge of the heavens, it appeared to me that an appropriate and interesting subject might be the present and future problems of astronomy. Yet it seemed, on further reflection, that, apart from the difficulty of making an adequate statement of these problems on such an occasion as the present, such a wording of the theme would not fully express the idea which I wish to convey. The so-called problems of astronomy are not separate and independent, but are rather the parts of one great problem, that of increasing our knowledge of the universe in its widest extent. Nor is it easy to contemplate the edifice of astronomical science as it now stands, without thinking of the past as well as of the present and future. The fact is that our knowledge of the universe has been in the nature of a slow and gradual evolution, commencing at a very early period in human history, and destined to go forward without stop, as we hope, so long as civilization shall endure. The astronomer of every age has built on the foundations laid by his predecessors, and his work has always formed, and must ever form, the base on which his successors shall build. The astronomer of to-day may look back upon Hipparchus and Ptolemy as the earliest ancestors of whom he has positive knowledge. He can trace his scientific descent from generation to generation, through the periods of Arabian and mediæval science, through Copernicus, Kepler, Newton, La Place, and Herschel, down to the present time. The evolution of astronomical knowledge, generally slow and gradual, offering little to excite the attention of the public, has yet been marked by two cataclysms. One of these is seen in the grand conception of Copernicus that this earth on which we dwell is not a globe fixed in the center of the universe, but is simply one of a number of bodies, turning on their own axes and at the same time moving around the sun as a center. It has always seemed to me that the real significance of the heliocentric system lies in the greatness of this conception rather than in the fact of the discovery itself. There is no figure in astronomical history which may more

[1] An address given by Prof. Simon Newcomb at the dedication of the Flower Observatory, University of Pennsylvania, May 12, 1897. Reprinted from Science, May 21, 1897.

appropriately claim the admiration of mankind through all time than that of Copernicus. Scarcely any great work was ever so exclusively the work of one man as was the heliocentric system the work of the retiring sage of Frauenburg. No more striking contrast between the views of scientific research entertained in his time and in ours can be seen than that seen in the fact that, instead of claiming credit for his great work, he deemed it rather necessary to apologize for it and, so far as possible, to attribute his ideas to the ancients.

A century and a half after Copernicus followed the second great step, that taken by Newton. This was nothing less than showing that the seemingly complicated and inexplicable motions of the heavenly bodies were only special cases of the same kind of motion, governed by the same forces, that we see around us whenever a stone is thrown by the hand or an apple falls to the ground. The actual motions of the heavens and the laws which govern them being known, man had the key with which he might commence to unlock the mysteries of the universe.

When Huyghens, in 1656, published his Systema Saturnium, where he first set forth the mystery of the rings of Saturn, which, for nearly half a century, had perplexed telescopic observers, he prefaced it with a remark that many, even among the learned, might condemn his course in devoting so much time and attention to matters far outside the earth, when he might better be studying subjects of more concern to humanity. Notwithstanding that the inventor of the pendulum clock was, perhaps, the last astronomer against whom a neglect of things terrestrial could be charged, he thought it necessary to enter into an elaborate defense of his course in studying the heavens. Now, however, the more distant objects are in space—I might almost add the more distant events are in time—the more they excite the attention of the astronomer, if only he can hope to acquire positive knowledge about them. Not, however, because he is more interested in things distant than in things near, but because thus he may more completely embrace in the scope of his work the beginning and the end, the boundaries of all things, and thus, indirectly, more fully comprehend all that they include. From his standpoint

> "All are but parts of one stupendous whole,
> Whose body nature is and God the soul."

Others study nature and her plans as we see them developed on the surface of this little planet which we inhabit; the astronomer would fain learn the plan on which the whole universe is constructed. The magnificent conception of Copernicus is, for him, only an introduction to the yet more magnificent conception of infinite space containing a collection of bodies which we call the visible universe. How far does this universe extend? What are the distances and arrangements of the stars? Does the universe constitute a system? If so, can we comprehend the plan on which this system is formed, of its beginning and

of its end? Has it bounds outside of which nothing exists but the black and starless depths of infinity itself? Or are the stars we see simply such members of an infinite collection as happen to be the nearest our system? A few such questions as these we are perhaps beginning to answer; but hundreds, thousands, perhaps even millions of years may elapse without our reaching a complete solution. Yet the astronomer does not view them as Kantian antinomies, in the nature of things insoluble, but as questions to which he may hopefully look for at least a partial answer.

The problem of the distances of the stars is of peculiar interest in connection with the Copernican system. The greatest objection to this system, which must have been more clearly seen by astronomers themselves than by any others, was found in the absence of any apparent parallax of the stars. If the earth performed such an immeasurable circle around the sun as Copernicus maintained, then, as it passed from side to side of its orbit, the stars outside the solar system must appear to have a corresponding motion in the other direction, and thus to swing back and forth as the earth moved in one and the other direction. The fact that not the slightest swing of that sort could be seen was, from the time of Ptolemy, the basis on which the doctrine of the earth's immobility rested. The difficulty was simply ignored by Copernicus and his immediate successors. The idea that nature would not squander space by allowing immeasurable stretches of it to go unused seems to have been one from which mediæval thinkers could not entirely break away. The consideration that there could be no need of any such economy, because the supply was infinite, might have been theoretically acknowledged, but was not practically felt. The fact is that magnificent as was the conception of Copernicus, it was dwarfed by the conception of stretches from star to star so vast that the whole orbit of the earth was only a point in comparison.

An indication of the extent to which the difficulty thus arising was felt is seen in the title of a book published by Horrebow, the Danish astronomer, some two centuries ago. This industrious observer, one of the first who used an instrument resembling our meridian transit of the present day, determined to see if he could find the parallax of the stars by observing the intervals at which a pair of stars in opposite quarters of the heavens crossed his meridian at opposite seasons of the year. When, as he thought, he had won success, he published his observations and conclusions under the title of Copernicus Triumphans. But alas! the keen criticism of his contemporaries showed that what he supposed to be a swing of the stars from season to season arose from a minute variation in the rate of his clock, due to the different temperatures to which it was exposed during the day and the night. The measurement of the distance even of the nearest stars evaded astronomical research until Bessel and Struve arose in the early part of the present century.

On some aspects of the problem of the extent of the universe light is being thrown even now. Evidence is gradually accumulating which points to the probability that the successive orders of smaller and smaller stars, which our continually increasing telescopic power brings into view, are not situated at greater and greater distances, but that we actually see the boundary of our universe. This indication lends a peculiar interest to various questions growing out of the motions of the stars. Quite possibly the problem of these motions will be the great one of the future astronomer. Even now it suggests thoughts and questions of the most far-reaching character.

I have seldom felt a more delicious sense of repose than when crossing the ocean during the summer months I sought a place where I could lie alone on the deck, look up at the constellations, with Lyra near the zenith, and, while listening to the clank of the engine, try to calculate the hundreds of millions of years which would be required by our ship to reach the star α Lyræ if she could continue her course in that direction without ever stopping. It is a striking example of how easily we may fail to realize our knowledge when I say that I have thought many a time how deliciously one might pass those hundred millions of years in a journey to the star α Lyræ, without its occurring to me that we are actually making that very journey at a speed compared with which the motion of a steamship is slow indeed. Through every year, every hour, every minute, of human history from the first appearance of man on the earth, from the era of the builders of the Pyramids, through the times of Cæsar and Hannibal, through the period of every event that history records, not merely our earth, but the sun and the whole solar system with it, have been speeding their way toward the star of which I speak on a journey of which we know neither the beginning nor the end. During every clock beat through which humanity has existed it has moved on this journey by an amount which we can not specify more exactly than to say that it is probably between 5 and 9 miles per second. We are at this moment thousands of miles nearer to α Lyræ than we were a few minutes ago when I began this discourse, and through every future moment, for untold thousands of years to come, the earth and all there is on it will be nearer to α Lyræ, or nearer to the place where that star now is, by hundreds of miles for every minute of time come and gone. When shall we get there? Probably in less than a million years, perhaps in half a million. We can not tell exactly, but get there we must if the laws of nature and the laws of motion continue as they are. To attain to the stars was the seemingly vain wish of the philosopher, but the whole human race is, in a certain sense, realizing this wish as rapidly as a speed of 6 or 8 miles a second can bring it about.

I have called attention to this motion because it may, in the not distant future, afford the means of approximating to a solution of the problem already mentioned—that of the extent of the universe. Not-

withstanding the success of astronomers during the present century in measuring the parallax of a number of stars, the most recent investigations show that there are very few, perhaps hardly more than a score, of stars of which the parallax, and therefore the distance, has been determined with any approach to certainty. Many parallaxes determined by observers about the middle of the century have had to disappear before the powerful tests applied by measures with the heliometer; others have been greatly reduced and the distances of the stars increased in proportion. So far as measurement goes, we can only say of the distances of all the stars, except the few whose parallaxes have been determined, that they are immeasurable. The radius of the earth's orbit, a line more than ninety millions of miles in length, not only vanishes from sight before we reach the distance of the great mass of stars, but becomes such a mere point that when magnified by the powerful instruments of modern times the most delicate appliances fail to make it measurable. Here the solar motion comes to our help. This motion, by which, as I have said, we are carried unceasingly through space, is made evident by a motion of most of the stars in the opposite direction, just as passing through a country on a railway we see the houses on the right and on the left being left behind us. It is clear enough that the apparent motion will be more rapid the nearer the object. We may therefore form some idea of the distance of the stars when we know the amount of the motion. It is found that in the great mass of stars of the sixth magnitude, the smallest visible to the naked eye, the motion is about three seconds per century. As a measure thus stated does not convey an accurate conception of magnitude to one not practiced in the subject, I would say that in the heavens, to the ordinary eye, a pair of stars will appear single unless they are separated by a distance of 150 or 200 seconds. Let us, then, imagine ourselves looking at a star of the sixth magnitude, which is at rest while we are carried past it with the motion of 6 or 8 miles per second which I have described. Mark its position in the heavens as we see it to-day; then let its position again be marked 5,000 years hence. A good eye will just be able to perceive that there are two stars marked instead of one. The two would be so close together that no distinct space between them could be perceived by unaided vision. It is due to the magnifying power of the telescope, enlarging such small apparent distances, that the motion has been determined in so small a period as the 150 years during which accurate observations of the stars have been made.

The motion just described has been fairly well determined for what, astronomically speaking, are the brighter stars; that is to say, those visible to the naked eye. But how is it with the millions of faint telescopic stars, especially those which form the cloud masses of the Milky Way? The distance of these stars is undoubtedly greater, and the apparent motion is therefore smaller. Accurate observations upon such stars have been commenced only recently, so that we have not

yet had time to determine the amount of the motion. But the indication seems to be that it will prove quite a measurable quantity and that before the twentieth century has elapsed it will be determined for very much smaller stars than those which have heretofore been studied. A photographic chart of the whole heavens is now being constructed by an association of observatories in some of the leading countries of the world. I can not say all the leading countries, because then we should have to exclude our own, which, unhappily, has taken no part in this work. At the end of the twentieth century we may expect that the work will be repeated. Then, by comparing the charts, we shall see the effect of the solar motion and perhaps get new light upon the problem in question.

Closely connected with the problem of the extent of the universe is another which appears, for us, to be insoluble because it brings us face to face with infinity itself. We are familiar enough with eternity, or, let us say, the millions or hundreds of millions of years which geologists tell us must have passed while the crust of the earth was assuming its present form, our mountains being built, our rocks consolidated, and successive orders of animals coming and going. Hundreds of millions of years is indeed a long time, and yet, when we contemplate the changes supposed to have taken place during that time, we do not look out on eternity itself, which is veiled from our sight, as it were, by the unending succession of changes that mark the progress of time. But in the motions of the stars we are brought face to face with eternity and infinity, covered by no veil whatever. It would be bold to speak dogmatically on a subject where the springs of being are so far hidden from mortal eyes as in the depths of the universe. But, without declaring its positive certainty, it must be said that the conclusion seems unavoidable that a number of stars are moving with a speed such that the attraction of all the bodies of the universe could never stop them. One such case is that of Arcturus, the bright reddish star familiar to mankind since the days of Job, and visible near the zenith on the clear evenings of May and June. Yet another case is that of a star known in astronomical nomenclature as 1830 Groombridge, which exceeds all others in its angular proper motion as seen from the earth. We should naturally suppose that it seems to move so fast because it is near us. But the best measurements of its parallax seem to show that it can scarcely be less than two million times the distance of the earth from the sun, while it may be much greater. Accepting this result, its velocity can not be much less than 200 miles per second, and may be much more. With this speed it would make the circuit of our globe in two minutes, and had it gone round and round in our latitudes we should have seen it fly past us a number of times since I commenced this discourse. It would make the journey from the earth to the sun in five days. If it is now near the center of our system it would probably reach its confines in a million of years. So far as our knowledge

of nature goes, there is no force in nature which would ever have set it in motion and no force which can ever stop it. What, then, was the history of this star, and, if there are planets circulating around, what the experience of beings who may have lived on those planets during the ages which geologists and naturalists assure us our earth has existed? Did they see at night only a black and starless heaven? Was there a time when in that heaven a small faint patch of light began gradually to appear? Did that patch of light grow larger and larger as million after million of years elapsed? Did it at last fill the heavens and break up into constellations as we now see them? As millions more of years elapse will the constellations gather together in the opposite quarter and gradually diminish to a patch of light as the star pursues its irresistible course of 200 miles per second through the wilderness of space, leaving our universe farther and farther behind it, until it is lost in the distance? If the conceptions of modern science are to be considered as good for all time—a point on which I confess to a large measure of scepticism—then these questions must be answered in the affirmative.

Intimately associated with these problems is that of the duration of the universe in time. The modern discovery of the conservation of energy has raised the question of the period during which our sun has existed and may continue in the future to give us light and heat. Modern science tells us that the quantity of light and heat which can be stored in it is necessarily limited, and that, when radiated as the sun radiates, the supply must in time be exhausted. A very simple calculation shows that were there no source of supply the sun would be cooled off in three or four thousand years. Whence, then, comes the supply? During the past thirty years the source has been sought for in a hypothetical contraction of the sun itself. True, this contraction is too small to be observed. Several thousand years must elapse before it can be measurable with our instruments. Granting that this is and always has been the sole source of supply, a simple calculation shows that the sun could scarcely have been giving its present amount of heat for more than twenty or thirty millions of years. Before that time the earth and the sun must have formed one body, a great nebula, by the condensation of which both are supposed to have been formed. But the geologists tell us that the age of the earth is to be reckoned by hundreds of millions of years. Thus arises a question to which physical science has not been able to give an answer.

The problems of which I have so far spoken are those of what may be called the older astronomy. If I apply this title it is because that branch of the science to which the spectroscope has given birth is often called the new astronomy. It is commonly to be expected that a new and vigorous form of scientific research will supersede that which is hoary with antiquity. But I am not willing to admit that such is the case with the old astronomy, if old we may call it. It is more

pregnant with future discoveries to-day than it ever has been, and it is more disposed to welcome the spectroscope as a useful handmaid, which may help it on to new fields, than it is to give way to it. How useful it may thus become has been recently shown by a Dutch astronomer, who finds that the stars having one type of spectrum belong mostly to the Milky Way, and are farther from us than the others.

In the field of the newer astronomy perhaps the most interesting work is that associated with comets. It must be confessed, however, that the spectroscope has rather increased than diminished the mystery which, in some respects, surrounds the constitution of these bodies. The older astronomy has satisfactorily accounted for their appearance, and we might also say for their origin and their end, so far as questions of origin can come into the domain of science. It is now known that comets are not wanderers through the celestial spaces from star to star, but must always have belonged to our system. But their orbits are so very elongated that thousands, or even hundreds of thousands, of years are required for a revolution. Sometimes, however, a comet passing near to Jupiter is so fascinated by that planet that, in its vain attempts to follow it, it loses so much of its primitive velocity as to circulate around the sun in a period of a few years, and thus to become, apparently, a new member of our system. If the orbit of such a comet, or in fact of any comet, chances to intersect that of the earth, the latter in passing the point of intersection encounters minute particles which causes a meteoric shower. The great showers of November, which occur three times in a century and were well known in the years 1866–67, may be expected to reappear about 1900, after the passage of a comet which, since 1866, has been visiting the confines of our system, and is expected to return about two years hence.

But all this does not tell us much about the nature and make-up of a comet. Does it consist of nothing but isolated particles, or is there a solid nucleus, the attraction of which tends to keep the mass together? No one yet knows. The spectroscope, if we interpret its indications in the usual way, tells us that a comet is simply a mass of hydrocarbon vapor, shining by its own light. But there must be something wrong in this interpretation. That the light is reflected sunlight seems to follow necessarily from the increased brilliancy of the comet as it approaches the sun and its disappearance as it passes away.

Great attention has recently been bestowed upon the physical constitution of the planets and the changes which the surfaces of those bodies may undergo. In this department of research we must feel gratified by the energy of our countrymen who have entered upon it. Should I seek to even mention all the results thus made known I might be stepping on dangerous ground, as many questions are still unsettled. While every astronomer has entertained the highest admiration for the energy and enthusiasm shown by Mr. Percival Lowell in founding an observatory in regions where the planets can be studied under the

most favorable conditions, they can not lose sight of the fact that the ablest and most experienced observers are liable to error when they attempt to delineate the features of a body 50,000,000 or 100,000,000 miles away through such a disturbing medium as our atmosphere. Even on such a subject as the canals of Mars doubts may still well be felt. That certain markings to which Schiaparelli gave the name of canals exist, few will question. But it may be questioned whether these markings are the fine, sharp, uniform lines found on Schiaparelli's map and delineated in Mr. Lowell's beautiful book. It is certainly curious that Barnard at Mount Hamilton, with the most powerful instrument and under the most favorable circumstances, does not see these markings as canals.

I can only mention among the problems of the spectroscope the elegant and remarkable solution of the mystery surrounding the rings of Saturn, which has been effected by Keeler at Allegheny. That these rings could not be solid has long been a conclusion of the laws of mechanics, but Keeler was the first to show that they must consist of separate particles, because the inner portions revolve more rapidly than the outer. The question of the atmosphere of Mars has also received an important advance by the work of Campbell at Mount Hamilton. Although it is not proved that Mars has no atmosphere, for the existence of some atmosphere can scarcely be doubted, yet the Mount Hamilton astronomer seems to have shown, with great conclusiveness, that it is so rare as not to produce any sensible absorption of the solar rays.

I have left an important subject for the close. It belongs entirely to the older astronomy, and it is one with which I am glad to say this observatory is expected to especially concern itself. I refer to the question of the variation of latitudes, that singular phenomenon scarcely suspected ten years ago, but brought out by observations in Germany during the past eight years, and reduced to law with such brilliant success by our own Chandler. The North Pole is not a fixed point on the earth's surface, but moves around in rather an irregular way. True, the motion is small; a circle of 60 feet in diameter will include the pole in its widest range. This is a very small matter so far as the interests of daily life are concerned; but it is very important to the astronomer. It is not simply a motion of the pole of the earth, but a wabbling of the solid earth itself. No one knows what conclusions of importance to our race may yet follow from a study of the stupendous forces necessary to produce even this slight motion.

The director of this new observatory has already distinguished himself in the delicate and difficult work of investigating this motion, and I am glad to know that he is continuing the work here with one of the finest instruments ever used in it, a splendid product of American mechanical genius. I can assure you that astronomers the world over will look with the greatest interest for Professor Doolittle's success in the arduous task he has undertaken.

There is one question connected with these studies of the universe on which I have not touched, and which is, nevertheless, of transcendent interest. What sort of life, spiritual and intellectual, exists in distant worlds? We can not for a moment suppose that our little planet is the only one throughout the whole universe on which may be found the fruits of civilization, warm firesides, friendship, the desire to penetrate the mysteries of creation. And yet this question is not to-day a problem of astronomy, nor can we see any prospect that it ever will be, for the simple reason that science affords us no hope of an answer to any question that we may send through the fathomless abyss. When the spectroscope was in its infancy it was suggested that possibly some difference might be found in the rays reflected from living matter, especially from vegetation, that might enable us to distinguish them from rays reflected by matter not endowed with life. But this hope has not been realized, nor does it seem possible to realize it. The astronomer can not afford to waste his energies on hopeless speculation about matters of which he can not learn anything, and he therefore leaves this question of the plurality of worlds to others who are as competent to discuss it as he is. All he can tell the world is:

He who through vast immensity can pierce,
See worlds on worlds compose one universe;
Observe how system into system runs,
What other planets circle other suns,
What varied being peoples every star,
May tell why Heaven has made us as we are.

THE INVESTIGATIONS OF HERMANN VON HELMHOLTZ ON THE FUNDAMENTAL PRINCIPLES OF MATHEMATICS AND MECHANICS.[1]

By Dr. Leo Koenigsberger.

Distinguished assembly, we are met to celebrate the anniversary of that day when an honored and enlightened ruler of this land infused new life into our university, and inaugurated that era of great scientific achievements of which we shall shortly commemorate a completed century.

At such a time our thoughts naturally turn with veneration and gratitude to our late illustrious rector, Von Helmholtz, who constantly strove with keenest interest and most energetic effort to broaden and strengthen the foundations of the prosperity and renown of this institution. Surely we can express our gratitude no more appropriately than by revering that great scientist, who during his administration was the pride and ornament of our university and our fatherland.

Thus we dedicate these festal hours to the memory of one of the greatest and most profound scientists of this century. I will ask you to regard his achievements from the standpoint of the mathematician, a science of which he was thoroughly fond, and which from this very place thirty-three years ago to-day he so clearly and beautifully described in these words:

> We see in the science of mathematics the conscious logical activity of the human mind in its purest and most perfect form. While we are impressed with the arduous labor of its procedure and the difficulty of forming and comprehending its abstract conceptions, we at the same time learn to confide in the security, reach, and fruitfulness of its reasonings.

It is but a short time since the whole world mourned the loss of Hermann von Helmholtz, who was associated with our university from 1858 to 1871, when at the height of his fame, and who, with Bunsen and Kirchhoff, made it a great center of scientific research.

[1] Lecture delivered on the occasion of the distribution of academic prizes, November 22, 1895, the birthday anniversary of the late Grand Duke Karl Friedrich, by Dr. Leo Koenigsberger, privy councillor of Baden, professor of mathematics and prorector of the University of Heidelberg. Translated from the original German, published by the University of Heidelberg. Universitäts-Buchdruckerei von J. Horning, 1895. pp. 51.

He who attempts to adequately describe the full significance of the service of Helmholtz to mathematical science must refer to each of his two or three hundred published writings, for all of them, even when mathematical language is not employed, excite the highest interest of the mathematician by reason of their eminently acute logical reasoning. But the difficulty of treating each research with full justice becomes apparent when we consider that the historian must follow his unparalleled investigations through all branches of natural science. In short, physiologist, physicist, mathematician, philosopher, and master alike of nature and art must he be who would regard so great a thinker as Helmholtz not merely with wonder and amazement, but fully and intelligently. It was not the nature of his mind to pursue mathematical investigations for their own sake, or to delight in the discovery of purely abstract truths deduced from algebraic or geometrical conceptions to find possible future use in the exact natural sciences. On the contrary, he obtained his mathematical problems direct from observation of nature, and this is certainly the only true way, yet fruitful only in the hands of so great a master. His starting point was the axiom that science, whose aim it is to apprehend nature, must admit that she is capable of being understood, and for him that meant no less than what his greatest pupil, Heinrich Hertz, has said: "The necessary logical consequences of the inner conceptions of outer phenomena should correspond with the necessary natural consequences of the phenomena conceived of, which requires that the problems of nature should be mathematically formulated." Thus in all his works appears an inexhaustible richness of results full of interest from a purely mathematical point of view, that nevertheless find a mechanical-physical significance, and then lead to the discovery of profound and general natural laws, which, when divested of their mathematical exposition, have prepared the way not only in the natural sciences, but also in the world at large, for essentially new conceptions of the procedure of natural events. He was interested in mathematical investigations for their own sake only in treating of the axioms and foundations of mathematical science. With this aim he made researches in each of the three great branches of mathematics—geometry, arithmetic, and mechanics—which have marked radical advances both in philosophy and in the whole development of mathematical physics. Here also, in contrast with the methods of other distinguished mathematicians engaged in the same or similar investigations, he continually verified his deductions by references to observation and experience in proceeding to attain the most abstract mathematical truths.

The science of mathematics in its whole extent, as I shall here regard it, deals with three independent primary conceptions, those of space, of time, and of mass. The province of geometry embraces considerations of space, that of arithmetic embraces time, and the relations of mass to space and time constitute the subject-matter of mechanics and mathematical physics. The view brought forward by Kant that space

and time are transcendental forms of perception which are more exactly determined by the axioms was almost universally accepted among mathematicians and philosophers till Helmholtz brought the matter so far within the scope of his investigations as to raise question with regard to the a priori existence of these axioms. His objections were based, not on the ground of abstract mathematical considerations, as had been the case in part with those of Gauss and Riemann, but physiological-optical researches had caused him to consider the source of the general perception of space, and he was very soon led to the conviction that only the appearance of space relations causes us to grant as self-evident that which, in reality, is a particular characteristic of our exterior surroundings, and we therefore regard the axioms of geometry as laws given by transcendental perception.

As early as 1852, in his academic dissertation, delivered at Konigsberg, "Upon the nature of human sensations," he showed by a thorough physiological-physical comparison of objects and their corresponding sensations, that light and color perceptions are only symbols for the actually existing relations; and thus he paved the way for further progress in the investigation of the nature of sense perceptions. According to what may be termed the "nativistic" theory of form perception, it is assumed that the retina itself discerns impressions with reference to its own surface, particular forms being therefore distinguished by means of an innate mechanism, and thus the special localization of each impression is given by the simple perception. Opposed to this is the empiric theory of which Helmholtz was the originator. By this theory, on the other hand, the sense-perceptions serve only as the symbols to our consciousness of outward things and events, whose significance is referred to our judgment. Following this theory it would, for example, be unnecessary that in the perception of difference of position there should be any similarity between the local sight-symbol for this interval and the corresponding external difference of position; or that in general an exact correspondence should exist between the laws of thought and perception and those of the outside world. These physiological-philosophical views were elaborated in a series of researches, interesting also from a mathematical standpoint, which appeared in the years 1862 to 1864 under the title "Upon the horopter." The horopter was defined by him as the geometrical position of those points in space whose images are formed upon corresponding parts of the two retinas, and therefore are perceived as single. The general form was found by him to be a curve in space of the third degree. Designating as a line horopter the surface upon which right lines of a given direction must lie in order that during a continuous congruent displacement upon this surface the images of the whole lines shall correspond, without necessary correspondence of the separate points, it was shown by Helmholtz that for the vertical and horizontal horopters, or for lines which in both fields

of vision appear normal or vertical to the retinal horizon, these surfaces were of the second degree. An exact mathematical discussion of them appeared in his Physiological Optics, with the addition of the assumption of the asymmetry of the retina and a somewhat modified definition of the identical points in the two retinas. Thus there was growing up within him the conviction, based on incontrovertible mathematical-physical reasoning, that since in the act of seeing there are two channels through which the sensations come separately to the brain, there to be blended to form a single perception of the material world, through an act of intelligence dictated by experience, it is altogether impossible to separate that part of our perception which corresponds to the simple sensation from that which is the result of experience. It appeared also that only in the relations of space and of time and of the function derived from them, number—that is, only in mathematics—is the outer and inner world the same, and that, therefore, here alone can a complete correspondence between the images and the things perceived be expected. The questions now arose, In what manner is this correspondence of space and time perceptions with the things which give rise to them brought about; what in these perceptions is a priori; what the result of experience, and what is the origin of space perceptions in general?

An investigation of these questions appeared in a memoir published in 1868, "On the data which form the basis of geometry." Helmholtz guarded himself perhaps from raising objections to Kant's conception of space as a transcendental form of perception; but he made himself clear as regards perception by means of the senses. Thus, for example, it results from the very organization of our eyes that all which we see must consist in a distribution of colors upon a surface, and this distribution of colors does not necessarily condition any particular series of phenomena of time or space. The question might then be raised whether for this form of transcendental space perception the assumption is involved that after, or at the same time with a given space perception, another determined by it must appear; or, in other words, whether the assumption of certain axioms is necessarily implied. In the endeavor to distinguish between the logical development of geometry and the results derived from experience, which are apparently necessary to the processes of thought, he recognized as the basis of all the demonstrations of the geometry of Euclid the proof of the congruence of figures in space, and therewith as a postulate the supposition that these figures can be brought together without alteration in their form or dimensions. He was then confronted with the question whether the assumption of the possibility of free movement, which we have experienced from our earliest youth, contains no logically unproved hypothesis, and by profound investigation of the question he was able to show with a very great degree of certainty that it did not.

Helmholtz depicted geometry limited to two dimensions, as it might

conceivably be, for example, to beings living on the surface of a solid body and without the ability to perceive anything outside of this surface. For us, dwellers in space of three dimensions, it is possible to conceive what manner of perceptions of space beings limited to two dimensions would have, though we can not, on the other hand, conceive of space of more than three dimensions, because all our means of perception extend only to tridimensional space. What would in the case of dwellers in two dimensions become of these axioms of our geometry: (*a*) Between two points only one shortest line, the straight line, can be drawn; (*b*) through three points not lying in a straight line a surface called a plane can be passed, such that all straight lines joining any pairs of points upon it lie wholly within the surface; and finally, (*c*) if two straight lines lying in the same plane, which never meet, however far produced, be defined as parallel, only one line parallel to these can be drawn through a point not lying upon either of them. What would become of these and of all the other axioms that require the continuity of geometrical figures? The surface dwellers would in general draw shortest lines between two points, which, however, would not necessarily be straight lines, and which Helmholtz called straightest lines. But in the simplest case, a sphere, an infinite number of straightest lines might be drawn between the two poles, though parallel straightest lines could not be drawn, and the sum of the angles in a triangle would be different from two right angles. These beings would, like us, find space endless though of finite extent, and in the development of a geometry they would have other axioms than we, but they could still move their figures about the sphere at will without altering their dimensions. Yet this peculiarity would in general be lost upon surfaces of other forms, since only those surfaces possess it, which have at all points a constant curvature, and of these, surfaces of a constant positive or negative curvature other than spherical are such as may be unwrapped from a sphere without bending or tearing, and may be called pseudospherical. An analytical investigation of surfaces of this latter kind shows that it is possible for straightest lines to be infinitely extended without ever returning to the surface, and that, as in the plane, only one shortest line is possible between two points. But the validity of the parallel axiom fails here, since through a point outside a straightest line an infinite number of other straightest lines may be drawn, which when infinitely extended do not cut the first. Thus the three axioms mentioned above are necessary and sufficient in order to characterize the surface for which Euclid's geometry holds in distinction from all other figures having two dimensions, as plane. Passing now to space of three dimensions and considering it as a domain of quantities in which the situation of any point may be determined by three measurements, we may compare it with other threefold extended subjects of consideration, such, for example, as the arrangement of systems of colors affords, in order to investigate whether we may discover special

characteristics of our space. Thus it may be shown that such peculiarities do indeed exist which depend on the completely free motion of solid bodies without change of form, and on the particular value of the measure of curvature. In the space under consideration this must be put equal to zero—as it is, among surfaces, for the plane alone and surfaces derived from it in order to give rise to the axioms of Euclid concerning the singularity of the shortest line and the essential conditions to parallelism. If the curvature was different from zero, triangles of great area would, it is true, have for the sum of their angles a value different from smaller ones; but the result of geometrical and astronomical measurements, which always gives the sum of the angles of a triangle as very near but never exactly equal to two right angles, warrants us only in the conclusion that the measure of curvature for our space is extremely small. It can not be proved that its value is zero—it is an axiom. Helmholtz went, however, still further. He showed that the consideration of a spherical or pseudospherical world developed by analogy from the plane might be extended in all directions, so that the axioms of our geometry throughout can not be fixed in their present form by our intuitive faculty. And he even made it appear plausible that if our eyes were provided with suitable convex glasses we might come to look upon the pseudospherical space as quite natural, and that we would be deceived in our estimations of size and distance only in the first few instances.

These researches formed in part the subjects of some lectures delivered in Heidelberg in 1868. Twenty years later he referred again in his article on "Shortest lines in the color system" to the results obtained by himself and Riemann. They found that all the characteristics of our particular kind of space may be derived from the fact that one may express the distance between two neighboring points in terms of the corresponding increments of their coordinates. To know the distance between two points of a solid it requires that these end points shall be completely given, and the distance shall remain constant through whatever movements and displacements the solid body be subjected. Analogously, Helmholtz proposed to determine colors by the quantities of three suitably chosen primary colors required to produce them, these primary colors taking the place of coordinates. In this analogy the conception of difference between two colors nearly alike corresponded to the distance between points in space. He deduced a very simple analytical expression which he hoped would play the same rôle in expressing the difference in hue that the formula for the length of the linear element does in geometry. This expression determined the variation in brightness and hue which occurs corresponding to a simultaneous change in the quantities of the three primary colors uniting to produce it. Analogously to the shortest line between two points he defined as the shortest series of colors that series of intermediate shades between given end colors of different brightness

and hue for which the sum of the perceptible differences is a minimum. This conception of the field of color sensation led him, in the memoir on "The extinction of the application of the law of Fechner in the color system," to extend this law, which contemplated only changes of brightness in a light of a constant color, to embrace a diversity of cases of more than one dimension, and to take into consideration the greatness of successive gradations of the tone and of the saturation of colors corresponding to change in the brightness.

In one of his last investigations "On the cause of the correct interpretation of sensory impressions," he returned again to the question of space perception, and was led to very acute and significant philosophical considerations upon the subject. The perception of the stereometric form of a material object played for him the rôle of one of a great number of cases of impressions derived through the senses which, quite independently of the geometrical definition, can only be brought together by an understanding of the law in accordance with which the perspective impressions follow each other. Starting with this view, he recognized our unconscious mental activity as the cause of the merging together of separate impressions with results essentially like those of our conscious thinking. According to Helmholtz, the conclusions of induction are nothing more nor less than the expectation that the phenomena observed in their beginning will proceed in a way corresponding with our previous observations, and false induction is identical with deceptions of our senses; so that our science is only the expression in words of such knowledge as, with our natural organization and with the help of the conclusions of induction depending on the unconscious activity of our minds, we are able to collect.

Long after the publication of his memoirs on the axioms of geometry he returned again to a similar subject in his investigation of the theory of the conception of number and measure, in a paper dedicated to Edward Zeller, in 1887, on the fiftieth anniversary of taking his doctor's degree. In this paper he opposed the view of Kant, that the axioms of arithmetic are laws given a priori, which determine the transcendental perception of time in the same sense that the axioms of geometry govern that of space. He investigated the significance and correctness of calculation with pure numbers and the possibility of their application to physical quantities. As he derived from considering numeration that we are able to retain in mind the order of succession in which acts of consciousness are performed, the science of pure numbers was for him essentially a method built up on physiological facts for the consistent application of a system of signs of unbounded capacities for extension and improvement, with the purpose of representing the different methods of combining these signs to reach the same final conclusion. After deducing from this conception a definition of the regular series of positive whole numbers and the significance of their succession, he proceeded to establish the conception of

addition of pure numbers, and showed that the axioms of arithmetic of the equality of two numbers in respect to a third, the association law of addition, and the commutation law, can only be proved by the agreement of the results arithmetically derived with those which can be obtained by counting of exterior numerable objects. That the objects should be numerable, certain conditions must be fulfilled concerning whose presence only experience can decide. Since that objects which in any particular respect are alike and can be numbered may be regarded as units of number, the result of their enumeration as a definite number, and the kind of units which compose it as the denomination of the number, the conception with respect to the equality of two groups containing given numbers of objects of the same denomination is given by these numbers. If we designate as quantities objects or attributes of objects which, when compared with similar ones, may be greater, equal, or less, and if we can express these quantities by known numbers, we call these numbers the values of the quantities, and the process by which we find them measurement. Thus we measure a force by the masses and displacements of systems upon which they have been exercised; or in dynamic measurements by the masses and movements of systems upon which they are working; or in the static method of measurement by bringing the forces into equilibrium with others already known. It only remains to consider under what circumstances quantities may be expressed by numbers and what is thereby attained in actual knowledge. With this purpose were instituted interesting and valuable considerations on physical equality and the commutation and association law for physical combination. Addition was regarded as a combination of quantities of the same kind, such that the result remained unchanged when the single elements were exchanged, or when the numbers were replaced by equal quantities of the same kind. In introducing irrational relations Helmholtz placed himself at the standpoint of the physicist, and in later development of the principles of mechanics he retained, as we shall see, the same point of view, showing that in geometry and physics no discontinuous functions are met with for which it is not enough to know with sufficient accuracy the bounds within which the irrational values lie. The mathematicians, however, it must be said, recognize functions of another kind, and the recent investigations of Boltzmann seem to point to a physical application of such analytical conceptions.

We now come to by far the most difficult part of our task as we attempt to describe the service of Helmholtz to analytical mechanics; for in order to understand the partial reconstruction of the science in consequence of some of his most brilliant researches it will be necessary to accurately follow him through his great series of wonderful mathematical-physical investigations and far-reaching physical discoveries in the great fields of hydrodynamics, aerodynamics, and electricity, which have contributed to the investigation of the axioms of mechanics.

Many physiologists of the time assumed, quite in defiance of the laws of mechanical natural philosophy, that through the action of the so-called life force the ordinary natural forces might be generated without limit. In his "Theory of the physiological heat phenomena" Helmholtz, starting from the proposition based on mechanical laws that a given quantity of a moving force can never by any complication of mechanism produce more than a definite corresponding quantity of motion, proceeded to discuss the question of the source of animal heat—so weighty in the theoretical consideration of life processes. The results of this investigation and of that simultaneously instituted "Upon the evolution of heat attending muscular action" gave him the verification of the great law of the conservation of energy which formed the subject of a lecture before the Physical Society of Berlin in the year 1847. It was certainly an interesting moment in the history of the sciences when thirty years ago to-day one of the most distinguished physicists of this century, Gustav Kirchhoff, in the course of his beautiful and luminous discourse "On the goal of the natural sciences," delivered from this spot, and in the presence of Helmholtz, declared the discovery of this law undoubtedly the most momentous which has been made in the province of natural science during the present century. Hertz also, in his posthumous work, "The Principles of Mechanics," asserts that physics at the end of our century has turned its preference to an entirely new method of thought, and, influenced by the tremendous impression made by Helmholtz's discovery of the constancy of energy, it is now preferred to refer all phenomena in their analyses to the laws of transformation of energy. For the sake of a proper appreciation of this great discovery of Helmholtz, as well as of his later fundamental researches upon the principles of mechanics, I must here briefly review the historical development of theoretical mechanics.

From the early investigations of the lever, the pulley, and the inclined plane, there were soon developed the general conceptions which are the basis of the science of equilibrium. With the definition of work as the product of a force by the infinitely small displacement of a material particle along the direction in which the force is measured arose the principle of virtual velocities, upon which rests the theory of statics. According to this principle, a material system is in equilibrium when for each virtual displacement—that is, a displacement compatible with the connection of the system of points—the total work done within the system is equal to zero. After the discovery of the inertia of masses by Galileo, and the conception of gravitation by Newton, the development of mechanics was founded upon the three famous laws of Newton. These may be stated as follows: (*a*) Every body remains in a state of rest or of uniform motion in a straight line unless compelled by outside force to change that state; (*b*) the acceleration of a material point by the action of a constraining force takes place in the direction in which the force acts and is equal to the

intensity of the force divided by the mass of the material point; and (*c*) the actions of two bodies upon each other are always equal and take place in opposite directions. From these laws there follows, for Newtonian forces at least, and with the assumption of a rigid connection between the points of the system, the principle of d'Alembert which holds sway in the whole province of dynamics. If we designate as supplied forces those which must be made to act at each point in order that it should move if separated from the system as it actually does move, then the principle of d'Alembert asserts that all the supplied forces suffice to maintain equilibrium, and thus furnishes the mathematician a method of determining for any moment the situation of all points of the system, when the constraints of motion of the points, the forces which act upon them, and the place and velocity of one of the points are known for the moment under consideration.

The advance of mechanics in this line was accompanied by the investigation of all the forces of nature—that is to say, the investigation of all the properties of matter—for we can know nothing of these except to recognize the forces which are there in play. After the discovery of these principles of equilibrium and of motion, it was the endeavor of scientists to obtain general laws and relations of motion. One of the most important and far-reaching of these in its consequences was the principle of the conservation of the so-called vis viva. If we define as the vis viva of a material point one-half the product of its mass into the square of its velocity, and the sum total of the vis viva for all points of a system in which the separate particles are connected by ties restraining their free motion as the kinetic energy of the system, then, for any system subject to the conditions of the d'Alembert principle, the increase of the kinetic energy attending the motion of the system from one situation to another is exactly equal to the work done by the various forces during the time interval in which the displacement occurs. If now the work done by the forces of the system during the displacement is dependent only on the initial and final situations, it follows that if the system returns again from the final to the initial condition the kinetic energy returns to its original value. This law is called the law of the conservation of the kinetic energy, and systems to which it applies are called conservative systems. A simple transformation of this law leads to the most far-reaching consequences. The fact that a body by its motion from one place to another does a certain amount of work necessitates that its capacity for performing work, or, in other words, its potential energy, was in its initial situation greater than in its final situation; so that for conservative systems the law of the conservation of kinetic energy goes over into the law of the constancy of energy. This may be expressed as follows: For any conservative system the sum of the potential and kinetic energies is unchangeable. It is important to remember the supposition upon which this is based, namely, that the work done by the motion of the system is dependent only on the initial

and final situations and not upon the intermediate positions. For the Newtonian forces, to which this principle is immediately applicable, the validity of this law means the impossibility of a perpetual motion; that is, the combination of natural bodies in such manner as to continually generate force without expenditure of work. For in the absence of this law we would be able, by a selection of the method by which we caused the system to return to its original condition, to save up some of the work done in its displacement, and thus, by repetition of the process, to generate mechanical energy out of nothing forever. The impossibility of such contrivances was long known, and the law of the constancy of energy established for forces of this kind; but not all the forces of nature seemed thus controlled. If a system moved through the same path first without, then with friction, the kinetic energy would, in the latter case, be diminished, owing to the smaller velocity, and thus it was necessary, to sustain the law of the constancy of energy in its generality, that the conception of potential energy, which had previously meant only energy of position, should be extended to other forms of energy, such as those which exist in heat and other natural phenomena.

In the case just cited, the loss in mechanical energy would require to be compensated by an equivalent quantity of heat energy developed by the friction. R. Mayer, starting with the presumption that the creation or annihilation of force is a matter lying outside the scope of human conception or achievement, asserted the equivalence of heat and mechanical work as the fundamental law of natural phenomena. Helmholtz, without knowledge of Mayer's researches, and including all natural forces within the circle of his investigations, followed out the assumption of the validity of the law of the constancy of energy, and was able to show, experimentally, the impossibility of a perpetual motion for a great series of physical phenomena where heat, light, electricity, and chemical affinity enter as acting forces. This is equivalent to the law that the work done by natural forces of all kinds during the passage of a system from one condition to another is dependent solely on the initial and final conditions without regard to the way in which the change is affected. From this he inferred that in any closed system every increase of energy involves an equal loss of energy, and thus achieved the great and comprehensive result that the energy of the world is constant.

With his customary remarkable modesty he emphasized the fact that it was his purpose simply to lay before physicists, in as complete form as possible, the theoretical and practical importance of the law of the constancy of energy, "whose complete verification must be regarded as one of the chief objects of physics in the immediate future." It deserves special emphasis that Helmholtz, in opposition to the followers of metaphysical speculation, who sought to establish the law of the conservation of energy from a priori considerations, declared the law, like all knowledge of the phenomena of the actual world, to be the result of induction,

and based upon the negative issue of numerous futile attempts to construct a perpetual motion. This great general law governing the quantitative relations which must subsist during all transformations, does not, however, determine whether work can be changed into heat without reserve, and vice versa, and the same uncertainty exists with regard to light, electricity, and other forms of energy. These are questions whose answer shall later exhibit the deep and comprehensive significance of the energy conception in mathematical physics.

After Helmholtz had investigated the physical aspects of this fundamental principle of mechanics from most varied points of view, he turned his attention to physiological researches growing out of his notice on the "Theory of acoustics," and from this to very general mechanical problems and special hydrodynamic investigations. In the year 1858 appeared his famous memoir "Upon the integrals of the hydrodynamic equations which correspond to wave motions." This research formed the foundation for an entirely new conception of the motions of fluids, which was later made fruitful in various branches of physics, notably by W. Thomson (Lord Kelvin) in his theory of vortex atoms, and by other physicists as well. Upon the assumption that for a perfect fluid—that is, one in which there is no friction between the particles—the pressure is equal in all directions. Euler and Lagrange had already obtained analytical relations between the pressure in the fluid, its density, the time, the coordinates of the particle under consideration, and, on the one hand, the velocity components; on the other, the position of this particle at the beginning of the motion. Further, they had inferred the so-called continuity equation, which required that the mass of a given particle of the fluid should not change with the time, therefore that the surface of the liquid should be continually composed of the same particles.

All these equations form for the perfect fluid the analogue of the principle of d'Alembert and lead to the determination of the variable quantities through the time and the original situation as a mathematical problem whose solution, to use an expression of Kirchhoff, would describe the motion. The problem can be solved for some particular cases in which the components of the velocity of each fluid particle may be placed equal to the differential coefficients of a determined function, which Helmholtz called the velocity potential, along the corresponding directions. This function, for incompressible fluids at least, has the same form as the potential of gravitating masses for points outside of them. But such a velocity potential does not always exist, and so Helmholtz attacked the extremely difficult problem of the forms of motion with complete generality in the memoir above referred to, which appeared in the year of his coming to Heidelberg.

First of all, he recognized that the change which an indefinitely small volume of fluid undergoes in an indefinitely small interval of time is composed of three different motions—a displacement of the

particle in space, an extension or contraction along three directions at right angles, and, finally, a rotation about a temporary axis. The existence of a rotation is, however, excluded when a velocity potential exists. Helmholtz designated forms of displacement, for which a velocity potential is not to be derived, as vortex motions. In determining the change in the velocity of rotation during the continuance of motion, he discovered that those particles of fluid which do not already possess rotation do not have such motions imparted to them in the progress of the disturbance. Defining a vortex line as a line whose direction is throughout coincident with the direction of the instantaneously existing axes of rotations of the particles along it, a remarkable law was deduced, which may be expressed as follows: A vortex line remains continually with the same particles, progressing with these particles through the fluid, and the value of the resulting velocity of rotation for any particle of the fluid varies directly with the distance of this particle from its neighbors in the vortex line. If, further, we designate as a vortex thread the portion of the fluid inclosed within an indefinitely thin mantle of vortex lines, the product of the velocity of rotation by the cross section of the vortex thread is constant throughout its whole length, and so remains during a progressive motion of the same. It follows that a vortex thread can never cease within the boundaries of the fluid, but must be either a closed ring wholly within the fluid or must continue to its boundaries. In the attempt to determine from the velocity of rotation the velocity of translation, Helmholtz succeeded by methods of great mathematical interest in making it possible to form a conception of the forms of motion, though the complete analytical solution of the problem was possible only in the simplest cases. Under certain preliminary circumstances relative to the nature of the surroundings, the vortex threads and vortex rings retain unchanged the same quantity of the fluid and are permanent. In this case it was shown that two vortex rings whose axes are the same and which have the same direction of rotation would proceed in the same direction, the foremost becoming distended and moving slower and slower, while the follower would concentrate itself and move faster, till finally—provided the velocities of translation lie within certain limits—the follower would overtake the leader, pass through it, and assume the rôle which the other played before. This procedure would, however, in the actual phenomena of vortex motions be very soon interrupted, owing to the friction.

The regularity and relative stability of vortex phenomena have led W. Thomson (Lord Kelvin) to put forward an interesting hypothesis in which the atoms are supposed to have the form of vortex rings, with the aim of uniting the theory of the continuity of matter and the atomic theory. He has also succeeded in connecting the results of the theory of vortex-atoms with the motion of solid bodies in fluids, and thus to join with those investigations which aim to eliminate action at

a distance from the province of physics. To this latter point I shall return in discussing later researches of Helmholtz.

Helmholtz soon became dissatisfied with his hydrodynamic investigations thus far referred to, and in the course of the preparation of his famous handbook of physiological optics he became convinced that, in order to eliminate the discordance between the results of theory and experiment in the investigation of the problems of motion of liquids, it would be necessary to take into consideration the friction between the liquid particles and the sides of the vessel. As the problem (due to some experiment of Bessel) of the vibrations of a pendulum ball under the influence of a surrounding liquid had already been treated, he investigated upon the basis of Bessel's observations, with the help of the already known equations of motion, the condition of the interior of a liquid mass which is subjected to the friction produced by the progressive rotary vibrations about one of its diameters of a pendulum ball consisting of a liquid producing friction. He succeeded in solving the problem mathematically, expressing the wave motions of the liquid produced by friction, and in this way was able to check the experimentally derived constants of viscosity for various liquids.

Two laws, important both theoretically and practically, were discovered by him, according to which, under certain circumstances, the flow of viscous liquids through cylindrical tubes is so divided into stationary streams that the loss in kinetic energy caused by the friction is a minimum; and in cases of equilibrium of a body swimming in a slow stationary stream the friction itself assumes a minimum value. Following this, in the year 1868, appeared his research, of great interest for the theory of functions, "On discontinuous fluid motions," in which he investigated still further the discharge of fluids and the formation of independent streams, and treated of the discontinuity of motion characteristic of fluid discharge and of the formation of vortices. Helmholtz assumed that from the nature of the problem—the determination of the origin of independent fluid streams—a discontinuity must necessarily be met with, and that therefore the fundamental hydrodynamic equations must admit the possibility of a discontinuous relation between the quantities appearing in them. In fact, in the motion of an incompressible fluid the pressure, whose diminution is directly proportional to the kinetic energy, becomes negative when the latter exceeds a certain value, and the fluid must be then torn asunder. It was shown that any geometrically completely sharp corner by which the fluid flows must, with fair velocities, cause a parting of the liquid, but that a blunted angle will only cause such a separation when the velocity is considerably greater. With the help of the methods of the theory of functions, the extremely difficult problem of the form of the independent streams was discussed. In this discussion it was assumed that, except for friction, no outside forces are acting, that the streams are stationary, that the velocity potential depends only on two coordi-

nates, and that the vessel and orifice have special forms. Finally, the value of the earlier results relative to vortices was shown for the determination of the motion of fluid particles in discharge.

In the early part of his stay at Heidelberg, and while engaged in his hydrodynamic researches, he was also pursuing acoustic and aerodynamic investigations. In his articles, "On combination-tones" and "Upon the tone color of the vowels," he again adopted the view of other physicists which he had abandoned in some of his earlier and less important works, namely, that each sensation, as it is aroused by the atmospheric vibrations going out from a single sounding body, is compounded from simple sensations or tones such as are caused by a simple vibratory motion of the air. This hypothesis he formulated mathematically, proceeding from the theorem of Fourier for the representation of any periodic motion as the sum of a series of sine-motions. The pitch of a tone was defined as the height of the lowest of its constituent tones, which is called the fundamental, the others being distinguished as overtones. Exact experimental investigation showed that the musical tone color depends only on the presence and strength, but not on the phase differences, of the overtones which are included in the sound. The sounds as they penetrate the ear could be resolved into their simple factors, and these could be again reunited. The sounds produced by the voice were found to differ from the sounds of most other musical instruments in that the strength of their overtones depends not on the corresponding cardinal numbers, but on their absolute pitch. Throughout these researches we may perceive the design to make a sharp distinction between the sensations in so far as they consist in impressions peculiar to our nerve apparatus, such as those due to overtones, and the perceptions which form our ideas of outside objects, as, for example, the ideas of the sound combined from the partial tones.

In all the previous considerations of acoustics the very far-reaching hypothesis had been made that the vibratory motions of the air, and other elastic bodies which are produced by the simultaneous action of several sources of sound, are always the exact sum of the motions due to all the separate sound-sources. Helmholtz, however, showed that this law only holds in strictness when the vibrations are of indefinitely small amplitudes, and therefore the density changes are so slight that they are negligible in comparison with the whole density, and the displacements of the vibrating particles are also negligible compared with the whole masses. A distinction was made between cases where this law was followed undisturbed both within and without the ear, but the sensations not accurately combined to form the perception, and cases where the combination tone was different from the summation of its constituents from causes operating before the auditory nerves are reached.

His studies in acoustics were soon pursued much further with the aid of the most refined analysis. In his famous treatise on the "Theory

of air vibrations in tubes with open ends" (1859) we find researches analagous to those in hydrodynamics already referred to. The question is raised in what way plane sound waves, excited within cylindrical tubes and corresponding to simple tones, are modified upon passing out into the free air.

This inquiry prepared the way to determine the form of vibration which finally results when the cause exciting the vibration operates regularly and continuously. The most important of the general laws of the potential function were found to be applicable to sound waves; for it was shown that when sound waves are excited at a point within a space filled with air their velocity-potential at any other position is the same as this quantity would be at the first point were waves of the same intensity excited at the second, and from this it follows that the phase difference is the same in both cases. Assuming certain restrictions in the dimensions of the opening, Helmholtz obtained the relation between the plane waves within the tube and the semispherical diverging waves in the free space at a distance, and thus was able to answer the inquiry with regard to the influence of the open end on the plane waves. Further investigation gave the positions of the maximum and minimum amplitude of vibration and the pitch of the tone of strongest resonance. He treated the difficult question for which of a series of forms of tubes the motion of the air in the orifice is characterized by the greatest wave length. In a later memoir it was shown that the results of calculation agree better with experiment when the interior friction of the air is taken into consideration.

All these results of his acoustical investigations, among which I have presented only those of the greatest mathematical interest, are contained in connected order in his famous work, "The study of tone perceptions as the physiological basis for the theory of music."

Among the many results important for the science of music, it may be mentioned that he distinguished in exact mathematical way between melody as the basis of music and harmony which serves only to increase the effect of melody, and that he found a mathematical foundation for the observation that for an harmonious union of several tones the rates of vibration must stand in a simple ratio, in the fact that the partial tones accompanying the fundamentals are disagreeable to the ear when their relative vibration numbers are not in a small, simple multiple of the ratio of the fundamentals.

Before proceeding to a short account of the much later aerodynamic investigations of Helmholtz, so far as they are of interest to mathematicians, some consideration is due a memoir on the border between hydrodynamics and aerodynamics which appeared in 1873 with the title, "On a theorem concerning geometrically similar motions of fluid bodies, together with an application to the problem of governing air balloons." Hydrodynamic equations were here employed to enable the production of results of observation obtained by the use of apparatus

of a certain size, and having a given velocity in a certain fluid to apparatus of another size and another velocity moving in a mass of another fluid of a similar geometrical form. The extension of the results analytically obtained for an incompressible liquid to gases led to a series of interesting applications. Thus Helmholtz found, among other things, that there is a limit to the size of birds beyond which the muscles would require to do more work in proportion to the mass than now. In the great vulture nature has probably reached the limit in size of a creature which shall be able to sustain itself for a long time in air, and thus man can have no hope by use of the most suitable wing-like mechanism, which he could move by muscular effort, to raise and sustain his weight in air. In applying the principle of comparison above mentioned to the construction of air balloons and ships the interesting result was reached that when the balloon weighs about half as much as the person propelling it the relation between working force and weight would be about the same as we are accustomed to see in steam war vessels.

In the years 1888–1890 Helmholtz extended his investigations of the motion of fluids in order to show how in masses of air discontinuous surfaces may result from the continuous action of forces. In these researches "on atmospheric movements" and "the energy of the waves and the winds" the inner friction of the fluids were taken account of, as in his former hydrodynamic investigations. After showing, by an exact mathematical treatment, that the effect of the friction at the earth's surface was very inconsiderable in the higher layers of air, that dissipation of the kinetic energy by friction was accomplished chiefly at the surface of the earth and at the surfaces of separation caused by rotary motions; and, further, that heat transference, excepting in the vicinity of the earth's surface and at the inner discontinuities, is effected only by radiation and by the convection of the warmer air particles, he raised the question why the circulation of the atmosphere is not accompanied by higher winds than actually do occur. He assigned as the reason that different layers of air are mixed by the vortices caused by the rolling together of discontinuous surfaces. In this way the layers become broken up and receive such a great extension of their surfaces that the transference of heat and the equalization of their motion through friction is much facilitated. A still more important cause of the breaking up and intermixture of the various layers of air is found in the regular march of waves through the atmosphere, which, as on water surfaces, is caused by the superposition of two layers of air of different specific gravities. The existence of such layers is only visible when the humidity of the under layer becomes so great that mists gather on the crests of the waves where the pressure is less, and then there appear strips of parallel clouds which extend over great regions of the sky. Helmholtz, therefore, was convinced that it was of the greatest importance to work out the theory of waves on the boundary

between two fluids, but on account of the great mathematical difficulty restricted the investigation at first to the simplest case of the motion of a rectilinear wave line which proceeds unchanged in form and with a constant velocity along the unlimited bounding surface between two fluids of different density. As a level water surface over which blows a wind of constant strength is in a condition of neutral equilibrium, and thus readily permits the creation of water waves, so it is with layers of air of different densities, except that here the phenomenon progresses on a vastly greater scale. Helmholtz, therefore, investigated the relations of energy and its division between air and water, and was led to very general mechanical speculations whose consideration will form the conclusion of our account. Very interesting but very difficult deductions were made, which established the difference between stable and labile equilibrium, and just as, long before, the condition of stable equilibrium for stationary bodies was found to be a minimum of the potential energy so for stationary waves with constant velocity-potential the condition of stable equilibrium was found to correspond to the minimum of energy.

I turn now to sketch the last great category of his mathematical physical labors, which led him finally to discoveries of the greatest significance for the principles of mechanics. I refer to his investigations in electricity, which began practically in 1870 and continued for ten years. Of these the most conspicuous are entitled, "On the equations of motion of electricity for stationary conductors" (1870); "On the theory of electro-dynamics" (1870–1874), and "Comparison of the laws of Ampère and of Neumann for the electro-dynamic forces" (1873). Most German physicists at that time deduced the laws of electro-dynamics from the hypotheses of Wilhelm Weber. These were founded on the laws of Newton for gravitational forces, and on Coulomb's law for static electricity, according to which the intensity of the electrical force transmitted with infinite velocity in all directions throughout space, is directly proportional to the product of the two acting electrical quantities and inversely as the square of the distance between their points of situation. The force is repulsive when the electrical charges are of the same kind, and attractive when they are of opposite kinds. Weber extended the assumptions of Coulomb by introducing besides the distance the velocity and acceleration with which the two electrical quantities approached or receded from each other. These suppositions of forces, which depend not simply on the distance but also on the motion of the points of action, seem now, to be sure, to contradict the results attained by Helmholtz in his earlier investigations, for he had showed that forces which depend on the distance and velocity in general infringe the general law of the conservation of energy, which holds as well for electro-dynamic as for other phenomena. But he had not at that time considered the complicated case of the laws of Weber, where the acceleration was introduced, and it can,

indeed, be shown that no reversible process can be derived from Weber's law by which work could be done without expenditure of energy. Besides the hypothesis of Weber, based on the action between electrically-charged points, there was the older one of F. E. Neumann, which considered not the action of one charged point upon another, but of one linear current element on another. This was regarded by Helmholtz as one of the happiest and most fruitful conceptions which the newer mathematical physics has produced. The law which can be deduced from the hypothesis of Weber for the mutual action of two linear current elements differs from the Neumann potential law, and Helmholtz found himself, in the course of his investigations, confronted with the question whether this hypothesis did in fact represent the true state of affairs and how both the law of Weber and that of Neumann were related to the laws of Maxwell, which I shall soon have occasion to mention.

He found that all these laws may be reduced to a common form and differ then only in the values of a constant which appears. All phenomena which are presented by the circulation of closed currents through metallic circuits can be accounted for equally well under any of the several hypotheses; but in the case of incomplete circuits they lead to considerably different consequences. For the purpose of deciding between these hypotheses, Helmholtz developed, with the help of his generalized induction law, the equations of motion of electricity in an extended conducting solid. He found that for a negative value of the undetermined constant, such as is required by the assumptions of Weber, a condition of neutral equilibrium of the electricity results, and thus there may be generated currents of infinite strength and the condition of infinite electrical density. The value zero required by Maxwell and the positive value required by Neumann for this constant do not, on the contrary, lead to these difficulties. These conclusions were subjected to many attacks, and their opponents sought both theoretically and experimentally to show that the hypothesis proposed by E. Neumann and extended by Helmholtz to form the fundamental law of electro-dynamic phenomena was incompatible with observation. There is, in fact, a difference between the potential law of E. Neumann for closed circuits when applied to incomplete circuits and the form of the induction law which Helmholtz had earlier derived. For the potential law ascribes electro-dynamic effect only to currents of electricity and their action at a distance, and not to the electrical charges put in motion with the conductors. Experiments show that this assumption is contradicted by the fact.

With wonderful acuteness of perception Helmholtz had from the start seen that the solution of all these questions could only be accomplished by the very difficult experimental investigation of incomplete circuits, and he was indeed uncertain that a solution would ever be obtained, since there might be no incomplete circuits, as the insulator

which intercepts the conduction of the current might itself be undergoing changes in the distribution of the electricity, so that apparently incomplete circuits might in reality be complete.

Faraday, who would not admit the existence of forces acting at a distance, because it appeared to him unthinkable that an action could take place between two separated bodies without change in the medium lying between, sought to find such a medium intervening between electrical or magnetic bodies. He succeeded in showing that in almost all bodies there exists magnetism or diamagnetism, and that in good insulators under the action of electric forces, a change may be observed, which he designated as dielectric polarization. If, now, one assumes with Faraday and with Maxwell, who mathematically stated this hypothesis, that in insulators there may be set up electro-dynamic activity by which these become dielectrically polarized, then the potential law follows from the complete theory without modification.

Partly before, partly during the progress of these important researches on the theory of electro-dynamics, Helmholtz pursued investigations on the laws of the division of electric currents in solid conductors and on electric boundary layers. In these investigations the theorem of the charging of a surface with electricity was extended with regard to electromotive forces for which a certain distribution of electrical potential upon the surface of a conductor may be predicted, which in all other adjacent conductors produces exactly the same currents as the given distribution of electromotive forces within the interior of the conductor. It was further shown that the previous assumption that electricity when in a state of equilibrium on one or more bodies leaves the interior of the bodies completely and is distributed in an infinitely thin surface layer, is only correct when we have to do with a single electrical boundary layer on a conductor which touches neighboring conductors or insulators without sudden changes in the potential function. In those cases, on the other hand, in which irregularities in the value of the potential function occur on the boundary between different bodies, as when two conductors under the influence of a galvanic force working between them touch each other, there is formed along the boundary surface an electrical double layer, whose significance for the phenomena which occur when liquids flow along a solid wall which they moisten was investigated.

In the meantime the conceptions of Maxwell, who, as already mentioned, following Faraday, replaced the notion of action at a distance by the action of the intervening medium, had become of deciding influence on the works of Helmholtz. In an investigation published in 1881 with the title "On the forces acting in the interior of bodies subjected to magnetic or dielectric polarization," Helmholtz showed that it is possible to determine the mechanical forces which act in the interior of bodies electrically or magnetically polarized without making any hypotheses regarding the inner constitution of the bodies. The

analytical treatment led him to expressions from which the forces at a distance completely disappeared and were replaced by the reactions of the polarized medium. He thus verified the conceptions of Faraday and Maxwell, who regarded the ether as the conveyer of tensions in space empty of ponderable substance, and who saw in the motions of electricity in conductors nothing else than the effects of the arising and passing away of polarization in the insulators. Helmholtz accepted these views still more completely in a memoir which appeared in 1882 "On systems of absolute measurement for electrical and magnetic quantities." In this investigation the theory of Faraday-Maxwell was given the preference over all other electro-dynamic theories which assume direct action at a distance having a magnitude and direction dependent on the absolute or relative motion of two electrical quantities. For these latter theories violate either the principle of the finiteness and constancy of energy or that of the equality of action and reaction; and first of all, in order to make the theory the basis only of conservative processes, exclude those phenomena in which, by reason of friction, heat is created and electrical or magnetic energy lost.

This research, in which, by reason of the observations of Faraday, he was confronted with the question whether actions at a distance really exist and must be taken into consideration, shows the wholly new train of thought upon which he was engaged and whose results were shortly to appear in discoveries of the greatest value for the principles of mechanics. But it was first necessary to pursue investigations in other branches of science in order to build thereon a treatment of the principles of mechanics which should embrace the laws of all the phenomena of nature. He therefore turned his attention to theoretical chemistry and published in 1882 a treatise "On the thermodynamics of chemical processes." In this the fundamental principles of the mechanical theory of heat were applied to chemical processes, and the generalized conception of the principles of mechanics is plainly visible, though appearing completely in physical form.

Since the loss of mechanical energy by friction creates heat, and a gain in mechanical energy implies the loss of heat; and since, further, the quantity of mechanical energy lost or gained is proportional to the amount of heat correspondingly gained or lost, it becomes natural to regard heat as a form of energy. The hypothesis may be made that each particle of a warm body is continually moving with varying direction and velocity in such a way that its place in the body remains sensibly unchanged. If this be the case, a part of the energy of a warm body must be in the form of kinetic energy, and energy of whatever kind transformed into heat must be measurable in that form. But the principle of the conservation of energy gives no indication whether work may be completely transformed into heat and heat retransformed into work without limit; and a similar uncertainty exists for all forms of energy. It was to this point of great theoretical and

practical interest that Helmholtz next directed his attention. He investigated how large a part of the heat developed in a galvanic cell by chemical processes appears in the work done by the current, and endeavored to arrange the different forms of energy in the order in which they may more or less completely be transformed into work. The previous experiments on the work equivalent of chemical processes had been concerned almost exclusively with the evolution or disappearance of heat accompanying the formation or solution of a compound, though in most chemical changes there are changes also in the condition of aggregation and density of the bodies, for which, also, work is performed or required. Since in most chemical processes the changes of melting, evaporation, etc., abstract heat from the surroundings, it becomes necessary to inquire what the work equivalents of these changes are. When one further considers that the chemical forces may produce not simply heat, but also other forms of energy without requiring that any of the change of temperature corresponding to the operation should enter into their production, it appears necessary that in the chemical processes a separation should be made between the parts of the forces of affinity which are directly changed to other forms of energy and those which generate heat. These two parts of the inner energy were designated by Helmholtz as free and combined; and he found that a chemical reaction proceeding from a state of rest, and at a constant temperature without the application of external work, can only go in such a direction that the free energy decreases. Thus, under the assumption of the universal application of the laws of the mechanical theory of heat, the value of the free energy decides in what sense chemical affinity shall act.

The calculation is only possible when the changes supposed are in the thermodynamic sense reversible. Helmholtz was led to consider under what circumstances, if at all, the latent heat of the gases set free by the decomposition of water would exert influence on the electromotive force of cells, but required, in order to pursue this inquiry, to first give analytical expression to the principles of thermodynamics. In previous applications of the conception of potential energy, changes of temperature had not in general been taken into account, either because the forces entering into the energy changes under evaluation did not materially depend on the temperature, such, for example, as gravitation, or else because the temperature remained constant during the cycle of events considered, or was a function entering into a mechanical change fully determined, as, for example, in the motion of sound waves the temperature may be considered as a function of the density of the gas. But when, as might be in the last case, the density is a function of the temperature, the arbitrary constant must be redetermined for each new temperature, and one can not make a transformation from one temperature to another.

Helmholtz showed that the thermodynamic equations require for

their formation only the differential coefficients of the so-called ergals, completely determined as a function of the temperature. For processes taking place at constant temperature the value of the potential function is thus determined, and this value he designated as the free energy. So that, if we call the difference between the total inner energy and the ergals the bound energy, this latter, divided by the temperature, gives the quantity termed entropy, already in use. In order to clearly distinguish what had in theoretical mechanics been called the vis viva or kinetic energy from the mechanical equivalent of heat energy, which was to be considered for the most part as invisible molecular kinetic energy, he called the first the kinetic energy of organized motion, defining organized motion—and this distinction is of fundamental significance for later works of Helmholtz—as such that the components of the velocity of the moving masses may be regarded as the differential coefficients of the space coordinates. Unorganized motion, on the other hand, is such that as in heat the motion of a single particle has no necessary similarity to that of its neighbor, and, on account of the relatively coarse means at our disposal, can not be directly transformed into other forms of energy. In this sense Helmholtz designated the value of the entropy as a measure of the disorganization. If a change of condition proceeding with constant entropy be defined as adiabatic, the entropy becomes the heat capacity for the heat generated during adiabatic processes at the expense of the free energy. For all changes of condition in which the temperature remains constant work is performed only at the expense of the free energy, the bound energy changing in amount at the expense of the heat entering and proceeding away. Assembling these results, it appears that all exterior work is done at the expense of the free energy, all evolution of heat is at the expense of the bound energy, and finally for each rise of temperature of the system free energy goes over in definite quantity and becomes bound. From this Helmholtz derived results on the emission and absorption of heat in the formation and breaking up of chemical compounds, which were substantiated by observations with galvanic elements.

In the last ten years of his life, from 1884 to 1894, he was occupied with his great researches on the principles of mechanics, in which he verified all the theoretical conclusions which he had derived in the course of his long and difficult investigations in the whole range of physics and physiology.

The general principles of mechanics, the principle of d'Alembert, the law of the motion of a material point, the law of surfaces, the principle of the conservation of kinetic energy, and the principle of least action were all proved with the assumption of Newtonian forces and rigid connection. It had later been found by observation that the laws so derived were much more general in their application in nature than followed from their proofs, and it had been on the one hand supposed that certain general characteristics of the Newtonian conservative

forces of attraction were common to all natural forces, while on the other hand it had been doubted whether, for example, the application of the principle of the equality of action and reaction was generally permissible. As already pointed out, the hypothesis had been made that action at a distance was resolvable into continuous dynamic reactions in an invisible intervening medium, thus establishing an analogy with the rôle of a spring or cord in the transmission of force. Since, however, it is the province of physics to refer the phenomena of nature to the simple laws of mechanics, the question arises first of all what constitute the first principles of mechanics, and what are, as Hertz has said, the final and simplest laws which each natural motion must obey, which no motion can ignore whose presence in nature is determined by our everyday experience, and from which as the fundamental principles of mechanics the whole science may be deduced without further reference to observation.

Until the pioneer researches of Helmholtz on the conservation of energy, mechanics, as has been remarked, following Galileo's conception of the inertia of masses, had been developed by application of the three laws of Newton. When, however, the whole structure was systematically and critically examined, a want of clearness was apparent in the definition of mechanical quantities, and the proofs of fundamental laws of statics, such as the laws of the parallelogram of forces and of virtual velocities, were found to be not altogether rigorous. Knowledge of the action of forces at a distance and of molecular, chemical, electrical, and magnetic forces was purely empirical.

The discovery of the principle of the conservation of energy made possible a consistent development of theoretical mechanics. The idea of force became less prominent, while mass and energy came forward as the indestructible physical quantities. Energy is present in two great divisions, of which the one—kinetic energy—is in all cases given by a constant function of the velocity of masses, while the other—the potential energy—is determined by the relative position of the masses, but must be derived in each case with consideration of their particular nature. The discussion of the different forms of energy, as well as of their mutual transformation, forms the subject of both physics and chemistry. In expressing the progress of phenomena as a function of the time, Helmholtz did not, like most of his predecessors, make the equations of motion the starting point from which to derive the genera principles of mechanics, because in this method it becomes necessary to make certain assumptions regarding the forces operating and regarding the limiting conditions of the problem, and these limitations exclude from the consideration a large number of possible motions. He proceeded, on the other hand, from the principle of least action, and by this means brought into the discussion many examples of relations between forces found in nature, but not occurring in treatises in which the former method is pursued.

These matters formed the contents of memoirs which Helmholtz published in 1886 and 1887 with the titles, "On the physical significance of the principle of least action," and "The history of the principle of least action." Hertz regarded these works at the time as marking the furthest advance of physics. Defining, after Leibnitz, the quantitative measure of the action following from the inertia of a moving mass as the product of the mass into the space traversed into the velocity, or as the product of the kinetic energy into the time, then the principle of least action requires that the total amount of the action shall have a limiting value in the passage from a given position of starting to a given position of rest. In performing the variation the coordinates of the points corresponding to intermediate positions of the system are varied simultaneously with the time in such a manner that the total energy of the system is not changed. This latter requirement can be satisfied by the condition that the energy at a given instant shall be the same for all variations as at the same instant in the unvaried motion, without regard to the magnitude of this latter, which it is possible might change in the course of a normal motion. In this way Lagrange and Hamilton have treated the problem. Jacobi, however, made the preliminary condition that the potential energy is independent of the time, and this requires that the amount of energy shall retain a definite value, in which case this relation may be used to eliminate the time increment from the action. Physically, Jacobi's restricting condition holds for a completely determined and closed system, while the Lagrange-Hamilton form of the equations of motion also holds true for an incompletely closed system, upon which variable outside influences are at work independent of the reaction of the moving system.

Hamilton, keeping the Lagrange conditions, has given the principle of least action another form in which it is called "Hamilton's principle." Defining the principal function of Hamilton as the difference between potential energy and the kinetic energy of the system, then the principle which bears his name requires that the negative mean values of the principal function, reckoned for equal time elements, shall have a definite value for a normal motion between given points.

But Lagrange, Hamilton, and Jacobi had proved the principle (first stated, but not proved by Maupertuis in 1744) only under the physical assumption of Newton's laws; and the motion of the points of a material system had been deduced from it under the condition of a rigid connection of the points, and with the express assumption of the principle of the constancy of energy. When Helmholtz had showed the general validity of the law of the constancy of energy, this last hypothesis remained a limitation no longer for cases in which all the forms are known in which energy equivalents are transformed during the progress of the change. It now remained to decide whether physical processes which depend not simply on the motions of determinate masses for which Newton's laws are applicable, but in which quantities of energy

come to consideration, may be treated by the principle of least action. As the forces of heat had already been referred to the hidden motion of conceivable masses, and as Maxwell had recognized the source of electrodynamic actions in the motion of unseen masses, Helmholtz wished to introduce the motion and energy of such hidden masses generally in physical problems. He recognized as antecedent to obscure phenomena motion and masses, which are to our senses invisible.

He chose Hamilton's principle for the expression of all motion, since it admits that upon a mechanical system whose inner forces may be determined as differential coefficients of force functions independent of the time, external forces may be exerted depending on the time. The work done by such forces is to be independently computed as not belonging to the conservative process, but dependent on other physical events.

Since, as Lagrange has showed, the outwardly directed forces of the moving system may be expressed through the principal function, Helmholtz called this the "kinetic potential," and thus by the principle of least action there follows this general characteristic of the progress of all physical phenomena: The negative mean value of the kinetic potential reckoned for equal time elements along the path is a minimum, or when longer intervals are considered it has a limiting value in comparison with all other neighboring paths which lead from the starting point to the end point in the same time. The kinetic potential goes over into potential energy for the case of a body at rest, and from the Hamilton principle it follows that for equilibrium the potential energy is a minimum. It was already known that when certain coordinates are represented in the value of the principal function only by their differential coefficients, and the corresponding forces are equal to zero, the Lagrange expression for the forces acting along the other coordinates becomes, analytically, exactly as in the general cases, a transformed principal function, which no longer as before contains the derivitives of the coordinates only in the second, but contains them also in the first degree. Thus, forms of the kinetic potential may appear in which the separation of the two forms of energy can not be recognized. Indeed, the kinetic potential may be any function whatever of the general coordinates and of the corresponding velocities. These facts led Helmholtz to inquire what form the principal function must take in order that the Lagrange expression for the external forces should remain unchanged. He found at once that this condition is satisfied when this function is increased by the sum of the products of the coordinates into the exterior forces expressed as a function of the time and resolved along these coordinates. This expanded expression for the law of least action gives the Lagrange formula for the forces immediately on performing the variation.

The importance of Lagrange's form of the equations of motion had already been shown by Helmholtz, since it is applicable to cases where

in addition to the potential and actual energy of weighable masses, thermal, electrodynamic, and electromagnetic equivalents of work appear. For he had expressed the laws of reversible heat processes in the form of Lagrange's equations of motion, and therefore through the law of the minimum characteristic value of the kinetic potential. It was found, however, that the temperature as a measure of the thermal motions did not, like the velocities in the kinetic energy of a ponderable system, enter into the expression only in the second power. Hence if it is desired to determine the general characteristics of systems which are governed by the principle of least action, the assumption must be abandoned that the velocities enter only in the values of the kinetic energy, in the form of homogeneous functions of the second degree, and the principle must be discussed under the supposition that the principal function is any function whatever of the coordinates and the velocities. The immediate occasion for these general considerations on the part of Helmholtz was the investigation of the form of the kinetic potential demanded for Maxwell's theory of electrodynamics, in which the velocities of electricity enter as a function of the second degree whose coefficients are not constants as in the measure of the value of the kinetic energy for ponderable systems, and where besides these appear linear functions of the velocity, whenever the action of permanent magnets comes into account.

Since the phenomena of light may be in the main explained under the hypothesis that the ether is a medium with properties similar to those of ponderable elastic solids, the principle of least action must be looked upon as applicable to the motion of light. Thus Helmholtz regarded the proper domain of this principle as far outreaching the bounds within which is included the mechanics of weighable bodies, and he held it as in the highest degree probable that it is the general law of all reversible natural processes. It is, moreover, to be noted that irreversibility rests not in the nature of things but in the limitations of our means of investigation, which do not enable us to reorganize unorganized atomic motions so as, for example, to reverse the motion of all atoms affected by the motions characteristic of heat.

The general validity of the principle of least action makes it of great value in formulating the laws of new classes of phenomena, in that it embraces in a single mathematical expression all the essential conditions of these phenomena. All cases of physical processes in which the kinetic potential contains the velocities in linear members were called by Helmholtz instances of hidden motion. It was shown that the principle of least action, as expressed in the above-mentioned general form, embraces the principle of the conservation of energy, and that the value of the energy may be determined from the values of the kinetic potential. As it does not, on the other hand, appear that in all cases where the constancy of energy is preserved the principle of least action is obeyed, the latter asserts more than the former, and

expresses a particular characteristic of the natural forces in consideration not included in the fact that they are conservative forces. The derivation of the value of the kinetic potential from the energy introduces arbitrary quantities which are homogeneous functions in the first degree of the velocities. This fact is of significance in that it shows that it is not possible with a complete knowledge of the relations of the energy to the coordinates and the velocities to find the kinetic potential and with it the laws of motion of the system, assuming that the principle of least action is followed. It is necessary in addition to these facts to discover the linear functions of the velocities which correspond to the hidden motions.

After developing some general correlated relations between the forces exerted by a system in different directions, as, for example, the thermodynamic law that if with rising temperature the pressure of a material system increases then compression will cause a rise of temperature, Helmholtz was able to show, at least for a restricted number of coordinates, that, conversely, the principal of least action is applicable when these correlated relations exist. Finally he derived both the total and partial differential equations of motion of Hamilton for the generalized form of the kinetic potential. From them he obtained a series of results for reversible motions of a system: that is, for such motions that the series of positions assumed in a positive motion should be reassumed in a return motion without the action of exterior forces, and with the same time intervals intervening.

We shall presently discuss further applications of the principle of least action as generalized by Helmholtz, and it need here only be remarked that Hertz discovers another generally valid law at the basis of this principle, which describes the motions of all systems directly. This law asserts that where the connections of a system can be dissolved for an instant all the masses of which it is composed will part asunder in rectilinear and uniform motions, but when such a dissolution is impossible the system will approximate to these preferred motions as nearly as possible.

The derivation of the characteristics of motion from the principle of least action involved great mathematical and physical difficulties and led Helmholtz to investigations described in "Studies upon the statics of monocyclic systems" (1884), and "Principles of the statics of monocyclic systems" (1884). These mark a distinct advance in the method of treatment of mathematical and physical problems, which has already, in the hands of Boltzmann, reached a commanding place in the theoretical physics.

When a system of bodies is affected with motion there is in general a change either in the position of the system in space or else in the condition of the bodies. This, however, is not necessary, as is exemplified in the passage of a long-continued current of electricity through a wire. In this case the position, the temperature, the magnetic condi-

tion in neighboring masses of iron, all remain at every point unaltered. Hence the motion which we regard as the cause of the phenomenon must in a sense be so far stationary that as soon as a particle leaves its place there must, within an infinitesimal time, be substituted another moving in the same direction with the same velocity, so that, in spite of the continual motion, there is at no point in space any apparent change. Helmholtz designated motions, such, for example, as the motion of a rotating top or that of a frictionless liquid in a circular canal, as cyclic. When all the motions of a system of bodies are cyclic, the system is said to be a cyclic system. Cyclic motions are generally hidden motions, since they do not alone cause a change in the appearance of the distribution of masses, and, conversely, hidden motions are usually cyclic. A coordinate is called cyclic when the whole condition of the system is not altered by changes in this coordinate. Since the kinetic energy of the system remains unchanged, it is not a function of a cyclic coordinate, but in general its differential is, since the kinetic energy is greater the faster the cyclic motion progresses. The condition of a system may be determined through other than cyclic coordinates, which Helmholtz called the slowly varying coordinates or parameters. These change so slowly that their differential coefficients with respect to time may be neglected, and the kinetic energy is therefore a function of the parameters, but not of their differential coefficients. When the parameters remain constant for a long period of time the motion taking place during the interval is cyclic. Systems are classified, according to the number of their cyclic coordinates, as monocyclic, etc., and are in general polycyclic.

The condition for the existence of a cyclic system can be fulfilled with any degree of approximation whenever the system possesses chiefly cyclic coordinates, provided the parts of the energy which are due to the velocity of change in the parameters are small in comparison with the parts which depend on the cyclic intensity, or in other words, provided the velocity of change of the parameters is negligible compared with that of the cyclic coordinates. The forces of a cyclic system are by definition independent of the velocity of change of its parameters, as follows immediately also from the Lagrange expression through the kinetic energy. It follows also that when no forces operate on the cyclic coordinates of a cyclic system the whole cyclic movement of the system, determined by the product of the mass by the velocity, is constant. In this case the motion is defined as adiabatic. The motions characterized by Helmholtz are defined in accordance with their properties as such that the potential and actual energy of the system are independent of a certain number of coordinates which would be necessary to completely determine the position of the system, but which are represented in the values of the energy only by their differential coefficients with reference to the time. This would also be the case with motions not strictly stationary when the changes in the

system were allowed to proceed so slowly that the system is never appreciably removed from conditions in which it might continuously remain. The motion of heat is not strictly monocyclic, for each atom probably continually alternates in the direction of its motion, and only in that an enormous number of atoms represent all stages of motion is the mechanical character of a monocyclic motion simulated.

Helmholtz raised the question under what general conditions the known physical characteristics of heat motion could be produced by other known classes of motions, and whether there is any special class of motions understood to be mechanical for which there exist restrictions to the transformation of work equivalents similar to the second law of thermodynamics. He extended the definition of a monocyclic system so as to include, besides those containing only one cyclic coordinate, others in which several such coordinates appear, but all but one of these functions are of another order of magnitude from the one under consideration. The very important and interesting case was discussed in which certain mechanical means are made use of to correlate the velocities in two monocyclic systems, these devices being of such a nature as to exert no influence when the motion proceeds with regularity, as desired, but which oppose with appropriate force any deviations from regularity. Helmholtz called a system of this sort, as for example two tops whose axes are so connected that they are forced to rotate with equal velocity, fettered, and the condition, the coupling of the system. He recognized in the device of coupling the only means of acting directly on the inner motion of monocyclic systems. Thus in heat motion we are debarred from influencing particular isolated atoms, and are forced to act without distinction on all contained within a given space. When, now, two originally independent monocyclic systems are by suitable regulation of exterior forces caused to assume a state corresponding to the conditions of a rigid connection, such a rigid connection may be inserted without disturbing the motion in progress, which continues in future as restrained by this linkage. In a similar way two bodies at equal temperature may be placed in contact without altering their inner motions, so that they retain equal temperatures while slow changes of temperature are made, and the equality is not prejudiced by pressure or action at a distance between the two systems upon coming together.

With the help of mathematical considerations quite analogous to those employed in thermodynamical investigations, Helmholtz showed in general that when monocyclic systems admit only of such mutual connections that the external forces of each separate system depend only on the momentary condition of the system, and not upon the beginning or ceasing of connection with other systems, then the coupling is a pure coupling of motion, and creates a new monocyclic system. When upon the beginning of interchange of internal motions between two or more systems the equilibrium of internal motion

between them requires that a certain function of the parameters—in heat, the temperature—should have the same value in all the systems, then the third property of heat expressed by the law of Carnot, namely, the restricted capacity for transformation, is here in evidence.

The three last memoirs of Helmholtz are in part in correction and in part in amplification of these investigations, fundamental for the principles of mechanics, on the principle of least action. They rest upon the conceptions worked out by Faraday, Maxwell, and Hertz, according to which the electrical oscillations in the ether are, in their velocity of propagation, their nature as transverse vibrations, and the consequent possibility of phenomena of polarization, refraction, and reflection, exactly analogous to the oscillations of light and heat, and constitute the method of performance of the apparent actions at a distance by conveying the force through the intervening medium.

In the memoir on "The principle of least action in electrodynamics" (1892), Helmholtz investigated whether the empiric laws of electrodynamics, as expressed in Maxwell's equations, may be brought into the form of a law of minima. Upon the ground of considerations already referred to, he was able to show that the ponderomotive forces could in fact be deduced from the generalized Hamilton principle in a form completely agreeing with Maxwell's theory. The energy was divided into two parts which played the same rôles toward one another as the potential and actual energy for ponderable masses. The electrical energy corresponded to the potential energy of masses at rest so long as no changes occurred in the moments or electric currents, while the magnetic energy corresponded to vis viva.

He penetrated still further in the electromagnetic theory of light, and proceeding from the consideration that the dispersion of light is brought about only at the boundaries of spaces which contain ponderable masses besides the ether, he sought, in an article which appeared in the year 1892, to explain the color dispersion with the aid of this theory. The mathematical theory of Maxwell requires that ponderomotive forces must exist along with the electric oscillations of the ether, which are capable of setting in motion heavy atoms which lie in the ether. Helmholtz showed that the material particles must also have charges of electricity, so that in the equations of motion to be formed the electric movements due to the electricity of each particle, since they are of different magnitude and direction, and are also affected by other than electrical forces—as, for example, inertia, friction, etc.—are to be distinguished from those in the free ether and particularly investigated in order to deduce the laws of color dispersion.

His general "Consequences of Maxwell's theory of the motions of the pure ether" (1893) is of very great interest. Capacity for motion is ascribed to the ether, and it is represented as receiving motions imparted to it by ponderable masses which permeate it, and as being thus moved along with them. Such mixtures occur in all substances

which are either conducting or refracting with respect to a vacuum, or have values of the dielectric and magnetic constants different from those of a vacuum. From the motions of the ponderable parts the corresponding motions of the ether may be determined. For space free from ponderable masses and filled only with ether, the question arises, if pure ether is free from inertia whether it makes way for the motion of material bodies through it, or penetrates them, remaining in either case wholly at rest, or whether it in part moves with them and in part makes way for their passage. Under the assumption that the ether has, mechanically considered, the properties of a frictionless, incompressible liquid, but without inertia, Helmholtz showed that the laws founded by Maxwell and elaborated by Hertz are sufficient to completely determine the laws of the changes and motions which take place in the ether. The recapitulation of the laws of electrodynamics under the principle of least action, as already made by Helmholtz, required for this purpose only the introduction of the hypothesis of uncompressibility. This would be accomplished by supplying in the expression for electrokinetic potential the left-hand member of the definition equation of incompressibility. In this way important conclusions could be drawn concerning the rise and decline of ponderomotive forces in ether at rest and in motion.

In an incomplete "Supplement to the paper: On the principle of least action in electrodynamics" (1894), Helmholtz returned once more to his recapitulation of the Maxwell-Hertz laws of electrodynamics in the generalized form of the principle of least action, in order to decide whether the observed values of the total energy of electromagnetic processes required the addition of a linear function of the velocities, and where this is the case to derive the expression for the ponderomotive forces from this principle.

Here ended the long series of brilliant mathematical and mathematical-physical researches of this incomparable investigator, which, so far as was possible without going deeply into the refinements of his mathematical analyses I have endeavored to outline before you, although certainly in an incomplete manner. What might have been the contents of the address which Helmholtz was preparing for the quadrennial scientific assemblage at Vienna with the title, "On continuous forms of motion and apparent substances," and of which he left but a few pages of manuscript for the introduction, will forever remain unknown to us. But one may well surmise that the world of science would have found there the philosophic kernel of the great researches which he carried out in the last years of his life on the foundations and principles of mechanics and physics.

PHYSICAL PHENOMENA OF THE UPPER REGIONS OF THE ATMOSPHERE.[1]

By Prof. ALFRED CORNU,

D. C. L., F. R. S., Officer of the Legion of Honor, Vice-President of the Academy of Sciences, Paris.

The primary and effective cause for almost all the physical phenomena that occur in the earth's atmosphere is the heat of the sun. The atmosphere may then be considered as an immense heating apparatus that has for its fire the sun, for its boiler the earth or the clouds heated by the solar rays, and for its condenser the radiation that occurs toward interplanetary space.

The means at the disposal of physicists and meteorologists for studying the different regions of the atmosphere are very limited; they are usually obliged to content themselves with very indirect observations and to proceed by induction. Most interesting phenomena do indeed occur in the upper regions at almost inaccessible heights. The purpose of this paper is to show by a few experiments that physical meteorologists are beginning to attain a true explanation of natural phenomena. You will see, indeed, that in certain cases they can not only exactly produce those phenomena, but often they are able to effect a true synthesis of them by using means in every way analogous to those actually operative in nature.

I will commence by enumerating the means in use among meteorologists for studying the different regions of the atmosphere.

The most direct method is founded upon the use of the aerostat. The aerostat, or balloon, allows us, in fact, to transport our meteorological instruments into the very midst of the atmospheric strata we wish to study.

Unhappily this method is difficult, expensive, and even dangerous; therefore it is employed only in exceptional cases. The aerostatic ascensions most productive of results have been those of Gay-Lussac (1804), of Glaisher (1862), and recently that of Dr. Berson of Stassfurt (1894), who ascended more than 9,000 meters.

[1] Translated from the Proceedings of the Royal Institution of Great Britain, Vol. XIV, pp. 638–648.

The most important facts observed from the balloon were entirely unexpected. I will briefly state them:

1. Clouds formed of ice crystals occur very frequently; they constitute the cirrus clouds that float at very great heights.
2. The direction of the wind changes at different heights.
3. The temperature does not always decrease regularly with the increase in altitude, cold strata and warm strata often alternating with each other.

The second method of studying the atmosphere is by the establishment of mountain observatories, upon isolated peaks when possible. At these stations the unexpected inversion of the temperature at various altitudes is daily verified.

The ice clouds are too high to be directly reached by mountain observatories.

A view of the principal mountain observatories of France will probably interest you.

Photographs of the following observatories were then thrown on the screen:

Pic du Midi (altitude 2,800 meters), in the Pyrenees.
Mont Ventaux (altitude 1,900 meters), in Provence.
Puy-de-Dôme (altitude 1,900 meters), in Auvergne.
Eiffel Tower (altitude 330 meters), at Paris.

This last observatory, thanks to the lightness of its construction of open work, may almost be considered as a captive balloon fixed permanently at 300 meters above the ground.

Halos.—Since ice clouds are situated at altitudes (6,000 to 10,000 meters) greater than that of the highest mountain observatories, we are condemned to the use of the balloon alone for all observations upon them. Fortunately the presence of ice crystals is revealed by an optical phenomenon that can be observed even at ordinary levels—the halo. This is a brilliant circle having a radius of about 22 degrees that surrounds the sun or moon. It has a reddish tint within and is slightly bluish at its outer border. It is explained, as are many appearances of a similar kind, by the refraction of the light of the sun or the moon in passing through icy needles. In fact the ice crystals are hexagonal prisms, the faces of which are inclined to each other, two by two, at an angle of 60 degrees. These, scattered through the air and facing in every direction, refract the light, but the refracted rays can not pass beyond the angle of 22 degrees imposed upon them by the minimum of deviation discovered by Sir Isaac Newton. The limit of the refracted rays is then a cone of 22 degrees around the line that passes from the eye to the luminous body.

Experiment imitating a halo.—By forming crystals in a transparent medium made by mixing appropriate liquids, there is exactly reproduced the mingling of the warm, moist strata of the atmosphere with the cold ones which produces ice crystals.

To do this place in a glass jar a saturated aqueous solution of potash alum, and send through the jar a luminous beam projecting the image of a circular opening like that of the sun upon the dark sky. Then

add to the contents of the jar a quarter of its total volume of rectified spirits; the alum, insoluble in the alcoholic mixture, precipitates in very minute crystals that float within the liquid. The image of the sun first becomes dim as in a fog, but soon a brilliant and slightly iridescent circle is seen, simulating very closely the appearance of a halo. The experiment is brilliant and instructive.

This phenomenon is well known to country people; it is a certain sign of rain when it appears during a warm day, even when no other sign predicts a meteorological disturbance.

Alteration and inversion of temperature.—In neighboring observatories situated at widely different altitudes, like those of Puy-de-Dôme and Clermont, we often find that warm currents exist in the upper regions. It is to successive inversions of this character that Mr. Amsler, of Schaffouse, attributes the beautiful phenomenon known in Switzerland as the "Alpenglühen," which consists in a renewal of the illumination of the snowy summits of the Alps some moments after the setting of the sun has darkened them.

There was thrown on the screen a photograph of the summits of the Bernese Oberland, the Jungfrau, the Mönch, the Eiger; the view being taken from St. Beatenberg, near the Lake of Thun. A picturesque imitation of the phenomenon just cited was given by means of a colored glass and suitable diaphragms.

The explanation of Mr. Amsler is founded on the change of direction of curvature that is given to the trajectory of the luminous rays according as the air at the bottom of the valleys is warmer or colder than that of the more elevated regions.

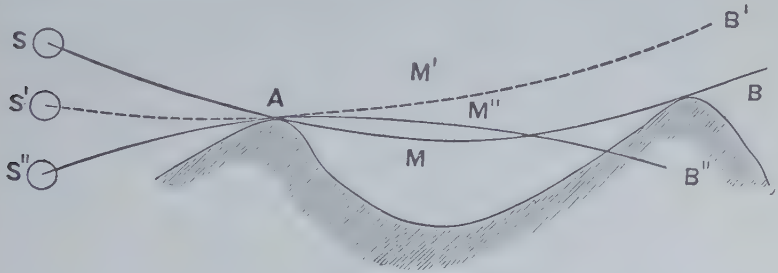


FIG. 1.

Before sunset, the earth's surface, heated by the solar rays, gives the trajectory a curvature, S A M B, like that of a mirage; that is, convex toward the earth; the sun, while setting at S′, causes the shadow of the summit, A, to be projected upon the summit, B, which it would seem ought henceforward to remain in shadow, since the sun continues to descend and its last ray is S′ A M′ B′. But if, during the interval, the air of the valley becomes sufficiently cool, the trajectory curves in the opposite direction, S″ A M″ B″, and the summit, B, is illumined anew.

Experiments showing the inversion of curves of luminous trajectories.—By using some care we can place in a transparent jar, 20 cm. in diameter, three strata of liquid, a lower one of chloride of zinc, heavy but

less refringent, and an upper one of diluted glycerin, lighter but also less refringent than the middle one. A movable mirror, LL, throws a beam of light through an opening, S, of a diaphragm. By throwing this beam in appropriate directions, it is reflected either from the upper or the lower stratum. A little fluorescein lights up the trajectories of the beams and makes their curvatures quite visible; we can thus represent the Alpenglühen with some accessory features.

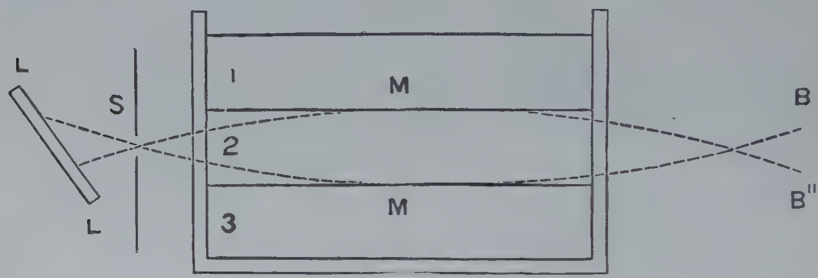


FIG. 2.

Scintillation of the stars.—This phenomenon is also a proof of the alterations of temperature and movement that occur in the higher strata of air. Spectrum analysis shows that the scintillation is produced by the disappearance of the successive colors of the spectrum following a somewhat regular course, according to the distance of the star from the zenith.

Imitation of this phenomenon.—A very striking experiment showing this can be made by projecting with a lens, L, the image of a luminous opening, O, upon a small silvered ball, B, 3 to 4 inches in diameter, placed upon black velvet. We thus obtain the appearance of a fixed star of remarkable brilliancy.

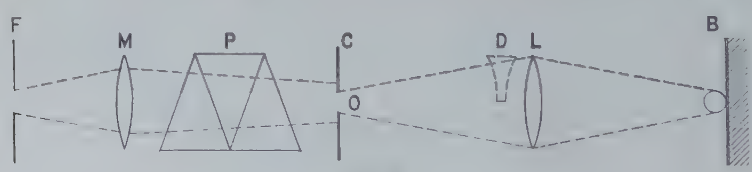


FIG. 3.

But the luminous opening, O, is made in a cardboard upon which is projected the spectral image of a slit, F, dispersed by a prism for direct vision, P. The cardboard, CO, is not exactly at the focus of the spectrum; that being formed farther away, in the plane of the lens, L. It hence results that the iridescent image of the slit in the cardboard has at its middle, where is placed the opening, O, a white region. The light thrown upon the ball, B, is therefore perfectly colorless. But on leaving the opening, the beam expands into a spectrum upon the projection lens, L, which recomposes it at B, as in the celebrated Newtonian experiment.

Then by shifting before the lens, L, a grating with large meshes, certain radiations are intercepted, and the star, B, appears colored.

A diverging half lens, D, having the same focus as L, annuls its effect, and the spectrum of the star, with the artificial bands caused by

the grating, appears on a white screen beside the ball. This is an imitation of the spectrum analysis of the scintillation of the stars.

We see by these few examples that the study of the optical phenomena of the atmosphere aided by physical analysis and synthesis, may and must teach us much concerning the calorific phenomena of inaccessible regions.

Dynamic phenomena of the atmosphere.—The phenomena we have hitherto studied are due to states of almost complete equilibrium in the atmospheric strata; we might call them static. But the calorific action of the sun, combined with the cooling action of radiation into space, may produce phenomena of movement presenting every degree of intensity, from the weakest to the most violent. We will call these dynamic phenomena.

They are manifested under very diverse forms:

1. Under the form of mechanical energy; which results in the formation of winds, whirlwinds, cyclones, waterspouts, etc.

2. Under the form of calorific energy; which results in the formation of clouds, rain, and hail, corresponding to the changes of state of water, the ever variable element of the atmosphere.

3. Under the form of electrical energy; lightning, thunder, etc.

In fact, the transformation of solar energy into mechanical energy is the fundamental phenomenon and the one that leads to all others. For the sake of brevity this is the only transformation that we will consider here.

The most simple mechanical phenomenon that is produced in the atmosphere is the wind. The wind has for its origin a difference of pressure between two more or less distant points. We have known since Pascal that the pressure of air is measured by the barometer. We might, then, think that the direction of the wind could always be determined by the indications of that instrument; that is to say, that the wind ought to go from the point where the barometrical pressure is greatest to the point where that pressure is least.

But, strange to say, this is almost never the case; the real direction of the wind is always oblique to that theoretical direction.

This fact has only been known for a few years. It has been put beyond doubt by the general meteorological charts which, conceived thirty years ago by Le Verrier, are to-day so widely circulated.

The wind seems to move around the point in the chart where the minimum is found, its direction, in the northern hemisphere, being the reverse of that taken by the hands of a watch, or in the same direction with the hands around the point of maximum pressure. In the southern hemisphere these directions are reversed.

In a word, the most ordinary movement of the atmosphere is a gyratory one, that which is called cyclonic.

This whirling movement of the air was noted long ago. We see it occurring quite frequently around us; dust and dead leaves are raised

by the wind in gyrations similar to the eddies of water in rivers. Sailors are acquainted with cyclones and water spouts, and dread their dangerous effects. On the American continent there are also observed terrible hurricanes, called tornadoes. These gyratory movements might appear to belong only to great tempestuous disturbances, but as we pursue in detail the study of the atmosphere we find that this kind of disturbance is met with in all the manifestations of displaced air. We conclude from this that the cyclonic movement is in some way the normal state of agitated air. It does not seem possible to use any force upon a gaseous mass without developing in it more or less rapid rotations that tend to become permanent.

Experimental proof.—Whenever we eject a strong jet of gas there are found about it one or more cyclonic currents. The cyclone takes the form of a ring if the ejected column is quite cylindrical, as is seen in the rings of smoke that occur after the explosion of cannon, guns, etc.

Here was shown the well-known experiment of producing fine wreaths of vapor by striking the canvas bottom of a box filled with vapors of ammonium chloride and having a circular opening in its top, the wreaths being rendered visible by placing them within the range of an electric light.

Multiple origin of the gyratory movements of the atmosphere.—Almost all the general causes that affect the movement of the atmosphere are gyratory influences; when the movement is once set up it continues of itself and sometimes increases. We ought to mention, in the first place, the rotation of the earth, which always involves a small component of rotation effecting the displacement of a gaseous mass in latitude or altitude. In the second place, and acting as a controlling cause, we have the solar heat, which warms the air near the ground or the clouds. As the ascensional force of the heated gas can not be uniform over all the surface exposed to solar radiation (both because of the nature and the configuration of the surface), there is a disturbance of the equilibrium at certain points, and columns of air tend to rise. We have then before us the case of the jets already cited, the conditions being favorable for gyrations around horizontal axes. When the gyration has once started, the causes that led to it keep it up and increase it.

The existence of whirlwinds with horizontal axes has been observed in hailstorms (in particular in the storm of May 20, 1893, at Pittsburg) by an American meteorologist, Mr. Frank W. Very, and has afforded him a very ingenious explanation of the formation of hail. Such a whirlwind, if it is of sufficient size, transports the warm, moist air from the surface of the earth into elevated cold regions. The moisture freezes, and the ice crystals are carried along in the gyratory movement; they alternately rise and fall, following the spirals of the whirlwind, and at every passage into the lower regions, charged with moisture, they increase in size. This explanation accounts for all the special phenomena that we observe in the fall of hailstones; their zonal

structure, their very low temperature, the peculiar noise before their fall, the electric phenomena that accompany them: for a whirlwind of hail is a true inductive electrical machine—a sort of replenisher.

Artificial reproduction of natural gyratory phenomena.—The phenomena produced by the rapid rotation of air are quite unexpected because of the singular behavior of the forces set in play. The ordinary laws of mechanics, familiar to us from our daily experience, appear to be entirely different from those which the cyclonic movements seem to obey. And this ought not to astonish us. We have reduced mechanics to its most simple elements; a material particle, a constant force, rectilinear motion. Thanks to these simplifications, we have well mastered the motion of spherical projectiles, of a pendulum, of the rotation of a fly wheel, etc. But as soon as the solid body becomes complex in form, whenever the movement that it may assume involves both translation and rotation, our imagination does not well seize it. If to the complication of form there is further added the resistance of the surrounding medium, we then have no longer any idea of the probable effect that will result. Witness the boomerang. As to the movements, they are so difficult for us to foresee that we are always surprised if we succeed in manipulating a vessel filled with water. As soon as the mass of liquid becomes somewhat considerable the tumultuous disturbance that we involuntarily cause in it always leads us to commit some awkward act.

You will see, then, how impossible it is that we should be able to predict the movements of the atmosphere, whose mass is immense, each cubic meter weighing 1,300 grams. If the energy expended in moving such masses is considerable, inversely the stability of the controlling forces is very great, since it must last until that energy is dissipated by passive resistance, almost all of which is due to friction against the earth's surface.

We will not seek, therefore, to analyze the forces involved in the gyratory movements of the air. I will confine myself to repeating before you some of the beautiful experiments of M. Ch. Weyher, who has been so kind as to come himself to assist me and to set up the apparatus that I now place before you.

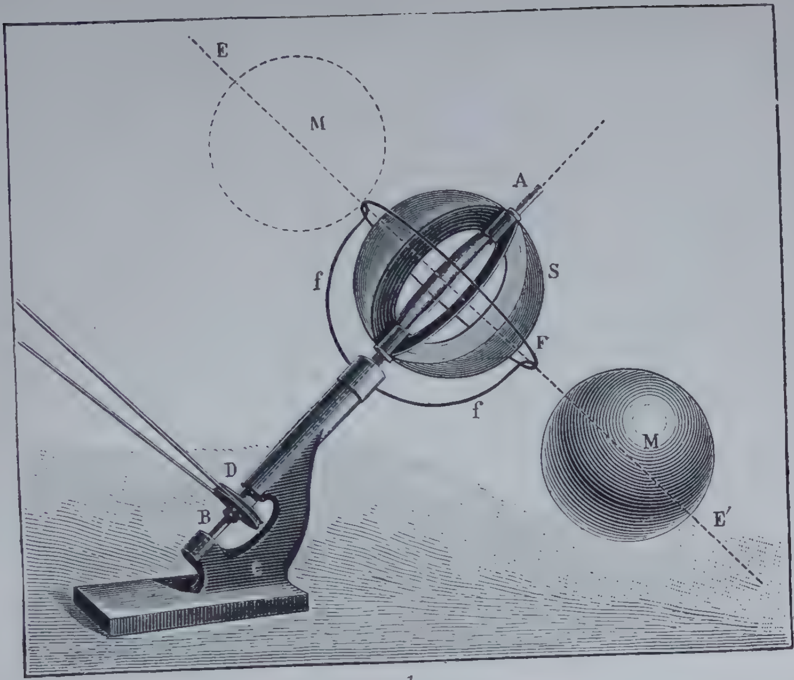
You see here a sphere composed of 10 semicircular blades, made to rotate rapidly around the axis AB (fig. 1, Pl. I). The air attracted by this rotation produces a general cyclonic movement symmetrical with reference to the plane of the equator. The air is drawn toward the revolving sphere from all sides, as may be shown by bringing near to it smoke or bits of paper. This air is expelled along the equatorial circumference, as you will see by these paper wreaths, which maintain themselves concentrically about the equator in a position that reminds one of the rings of Saturn, the tension of the paper and its rapid vibration clearly showing that it is the repulsion of the equatorial current that maintains them.

It might be supposed from this that equatorial repulsion only can be produced by such a revolving sphere; but the complexity of cyclonic movements baffles our most assured expectations. If we bring near the sphere a light ball, it is strongly attracted and commences to turn rapidly about the moving sphere in the equatorial plane. A second, a third, launched in the same way, follow it with varying velocity and represent satellites. The planetary similitude is then complete.

This paradox of a repulsion changed into attraction by changing the form of the body presented is easily understood when we consider the resultant of the attractive and repulsive forces on the surface of the movable body. Cyclonic attraction dominates throughout a greater angular extent around the revolving sphere. This can be easily proved by placing below the sphere a basin full of hot water. If the air of the room is quite calm, we see the steam gradually unite into a whirling column extending from the surface of the water to the revolving sphere. This is an imitation of a waterspout. The importance of this phenomenon has led M. Weyher to reproduce it in a more striking form, using a much greater amount of mechanical energy, corresponding more nearly to that which occurs in nature.

The gyratory movement, which in nature has its source in the upper regions of the atmosphere, is set up by a fan placed three meters above a vessel of water 4 meters in diameter (fig. 2, Pl. I). When the fan is made to revolve (400 to 500 revolutions per minute) the aerial cyclone thus formed reaches gradually the surface of the water, which is seen to be agitated, forming centripetal spirals that unite in a cone several centimeters in height. Above this cone there forms a sheaf of droplets that fall back with a whirling motion. This attraction at a distance is rendered still more striking when the water is slightly heated. The steam then forms a hollow tube, the empty part of which is distinguished by its dark tint and its geometrical regularity. It passes from the surface of the water toward the fan, raising light objects like bits of straw that float on the liquid.

Such is the experiment that was made in the open air at the works of the Société Weyher et Richmond in 1887. With the smaller apparatus which you see here (fig. 3, Pl. I) we can repeat it under equally conclusive conditions. The fan is placed at the upper part of this case, which is 2 meters high and provided with a glass front. The water, slightly heated and containing a little soap, is placed in a basin at the bottom of the case. As soon as I set the fan going you observe the agitation of the water, the soap bubbles rushing toward the foot of a column of steam. Soon that column takes on the form described above and simulates exactly the appearance of a natural waterspout. Below we see the "bush"—that is to say, the sheaf-like arrangement of bubbles: above, the hollow funnel of steam. A light ball placed on the surface of the water is first drawn toward the center of disturbance and caught at its foot. By increasing the velocity of rotation (which



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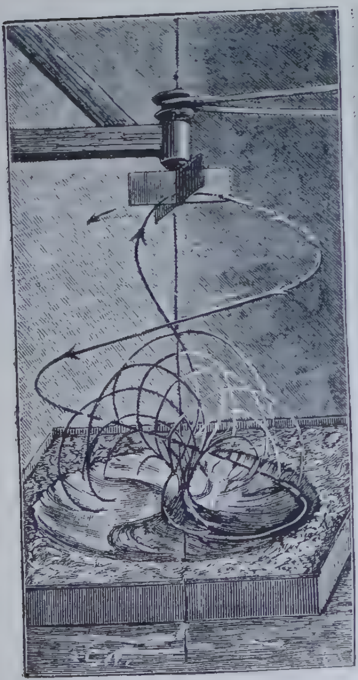

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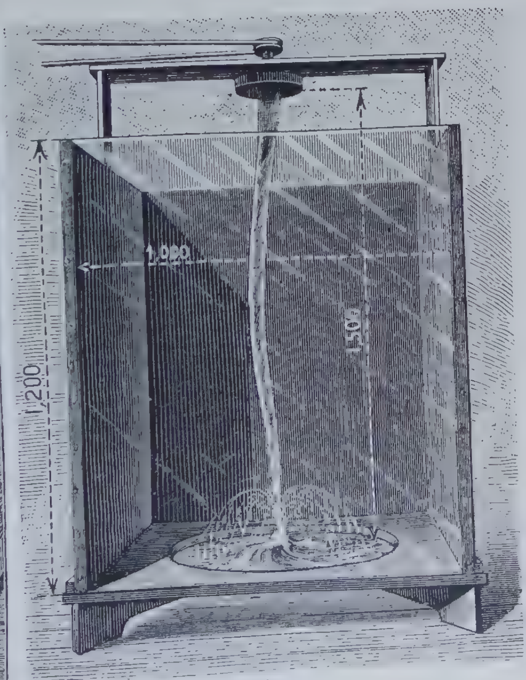

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PHYSICAL PHENOMENA OF UPPER ATMOSPHERE.

increases the power of the cyclone) the ball is raised by the waterspout, sometimes following the funnel throughout its entire height.

The helicoidal movement of this light ball, as well as the appearance of the nebulous funnel, show very well how the waterspout is formed. We can see the whorls of helicoidal currents superposed on each other, some going up, others going down. There is a perpetual passing and repassing between the fan and the surface of the water. As all the currents turn in the same direction, if those going up describe right-hand helices, those going down describe left-hand helices. It is the failure to recognize this double movement of ascent and descent that has kept up the misunderstanding between the partisans of the ascending spouts and those who claim that they are always descending.

The ascensional movement of the light ball drawn into the spout shows the upward velocity very well. It is more difficult to demonstrate the downward motion, which some theorists consider the only one, because the space in which it acts when the experiment is shown on this reduced scale is quite contracted, being confined to the very interior of the nebulous envelope, where a dark color shows a central cavity. Still I shall be able to demonstrate this movement by means of a very simple device. I place at the upper part of the spout a body that emits smoke. We see that this smoke is soon drawn into the spout, is twisted into a long, pointed cone, and descends toward the surface of the water. This is exactly what is seen in nature when in a marine waterspout the clouds descend in the form of a funnel that attaches itself to the "bush" formed by the water on the surface of the turbulent ocean. This funnel might be called the safe portion of the spout. The dangerous part is invisible, being the envelope of air that whirls about this funnel. In the experiment you see before you the reverse is the case. The cyclonic envelope is quite visible, thanks to the steam that has been supplied. The internal funnel remains dark. By introducing the smoke we verify its existence and form.

I could proceed to show you that with a similar apparatus it is possible to reproduce a cyclone with all its peculiarities. The variations of pressure at the time of its passage—the low barometer, the central calm, the sudden outburst of the wind, the eye of the storm, etc.—all these M. Weyher has demonstrated. But time is wanting. The experiments you have just seen will suffice, I hope, to show how complete these experimental syntheses are and how they reproduce natural phenomena even in the most minute details.

I will conclude by merely calling your attention to the great gain, both in extent and certitude, that must accrue to meteorology by its becoming an experimental science.

NEW RESEARCHES ON LIQUID AIR.[1]

By Professor DEWAR, M. A., LL. D., F. R. S., M. R. I.

Of all the forms of engineering plant used in low-temperature research, the best and most economical for the production of liquid air or oxygen is one based on the general plan of the apparatus used by Pictet in his celebrated experiments on the liquefaction of oxygen in the year 1878. Instead of using Pictet's combined circuits of liquid sulphur dioxide and carbon dioxide, maintained in continuous circulation by means of compression, liquefaction, and subsequent evaporation, it is preferable to select ethylene (after Cailletet and Wroblewski) for one circuit, and for the other either nitrous oxide or, better, carbon dioxide. Further, instead of making highly compressed oxygen to be liquefied by heating potassium chlorate in an iron bomb directly connected with the refrigerator, it is safer and more convenient to use gas previously compressed in steel cylinders. The stopcock that Pictet employed to draw off liquid and produce sudden expansion was in his apparatus placed outside the refrigerator proper, but it is now placed inside, so as to be kept cool by the gases undergoing expansion. This improvement was introduced along with that of isolating the liquid gases by surrounding them with their own cooled vapor in the apparatus made wholly of copper, described and figured in the Proceedings of the Royal Institution for 1886. In all continuously working circuits of liquid gases used in refrigerating apparatus, the regenerative principle applied to cold, first introduced by Siemens in 1857, and subsequently employed in the freezing machines of Kirk, Coleman, Solvay, Linde, and others, has been adopted. Quite independently, Prof. Kamerlingh Onnes, of Leyden, has used the regenerative principle in the construction of the cooling circuits in his cryogenic laboratory.[2] Apart, therefore, from important mechanical details and the conduct of the general working, nothing new has been added by any investigator to the principles involved in the construction and use of low-temperature apparatus since the year 1878. Detailed drawings of the Royal Institution

[1] Read at weekly evening meeting of Royal Institution of Great Britain, March 27, 1896, Edward Frankland, esq., D. C. L., LL. D., F. R. S., vice-president, in the chair. Printed in Proceedings of the Institution, Vol. XV, February, 1897, page 133.

[2] See paper by Dr. H. Kamerlingh Onnes on the "Cryogenic laboratory at Leiden, and on the production of very low temperatures," Amsterdam Akademie, 1894.

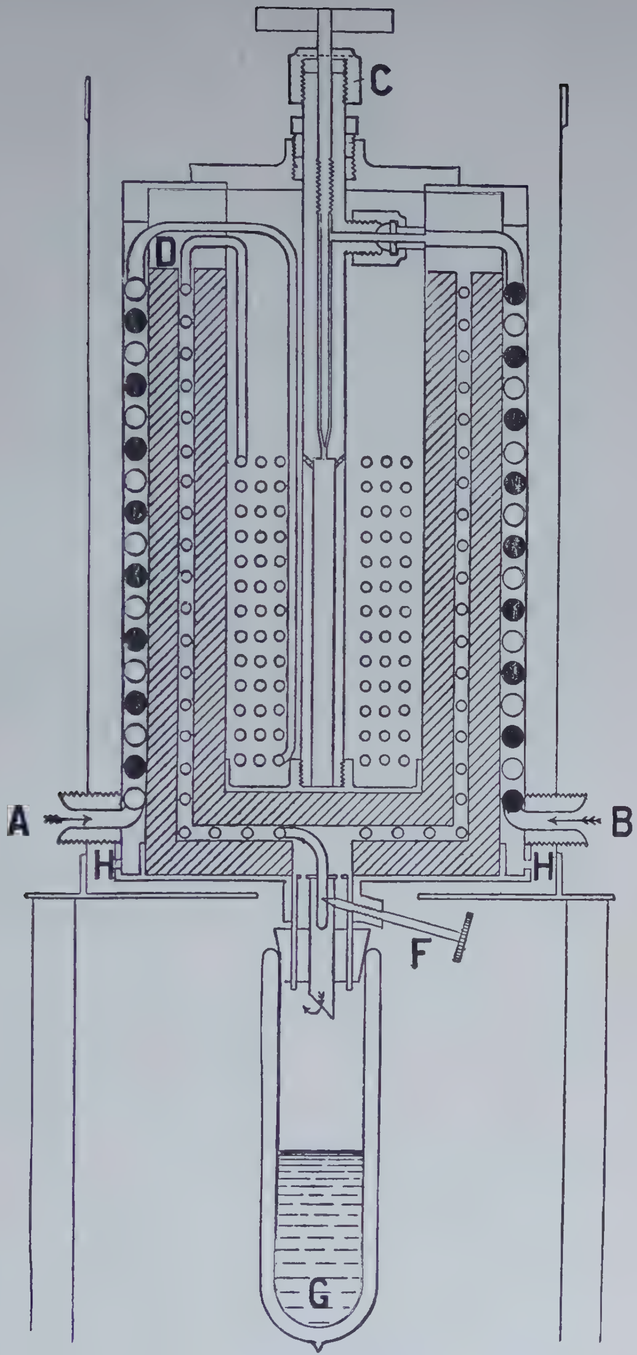
refrigerating plant now in use have not been published, simply because changes are constantly being made in the apparatus. Science derives no benefit from the description of transitional apparatus when there is no secret about the working process and how to carry it into effect. The Philosophical Magazine of February, 1895, contains a fantastic claim put forward by Professor Olszewski, of Cracow, that because he used in 1890 a steel tube combined with a stopcock to draw off liquid oxygen he had taught the world, to use his own language, "the method of getting large quantities of liquid gases." In addition the professor alleges, four years after the event, that the experiments made at the Royal Institution are chiefly borrowed from Cracow, and that he is entitled to the credit of all low-temperature research. As to such claims, one can only wonder at the meager additions to knowledge that in our time are unhesitatingly brought forward as original, and more especially that scientific men could be got to give them any currency in this country. Such persons should read the late Professor Wroblewski's pamphlet entitled "Comment l'air a été liquéfié,"[1] and make themselves generally acquainted with the work of this most remarkable man before coming to hasty conclusions on claims of priority brought forward by his sometime colleague.

Liquefying apparatus.—A laboratory apparatus for the production of liquid oxygen and other gases is represented in section in Plate II. With this simple machine 100 cc. of liquid oxygen can readily be obtained, the cooling agent being carbon dioxide, at the temperature of —79°. If liquid air has to be made by this apparatus, then the carbonic acid must be kept under exhaustion of about 1 inch of mercury pressure, so as to begin with a temperature of —115°. Under such conditions the yield of the liquid gases is much greater. The gaseous oxygen, cooled before expansion by passing through a spiral of copper tube immersed in solid carbon dioxide, passes through a fine-screw stopcock under a pressure of 100 atmospheres, and thence backward over the coils of pipe. The liquid oxygen begins to drop in about a quarter of an hour from starting. The general arrangement of the circuits will be easily understood from the sectional drawing. The pressure in the oxygen cylinders at starting is generally about 150 atmospheres, and the best results are got by working down to about 100. If a small compressor is combined with the apparatus, the liquefaction can go on continuously. This little apparatus will enable liquid oxygen or air to be used for demonstration and research in all laboratories.

Vacuum vessels.—It has been shown in previous papers[2] that a good exhaustion reduces the influx of heat to one-fifth part of what is conveyed when the annular space in such double walled vacuum vessels is filled with air. If the interior walls are silvered, or excess of mercury

[1] Paris, Librairie du Luxembourg, 1885.

[2] "On liquid atmospheric air," Proc. Roy. Inst., 1893; "Scientific uses of liquid air," ibid., 1894.



LABORATORY LIQUEFACTION APPARATUS FOR THE PRODUCTION OF LIQUID OXYGEN, ETC.

A, air or oxygen inlet; B, carbon dioxide inlet; C, carbon dioxide valve; D, regenerator coils; F, air or oxygen expansion valve; G, vacuum vessel with liquid oxygen; H, carbon dioxide and air outlet; ○, air coil; ●, carbon dioxide coil.

is left in the vessel, the influx of heat is diminished to one-sixth part of the amount entering without the metallic coating. The total effect of the high vacuum and silvering is to reduce the ingoing heat to one-thirtieth part, or, roughly, 3½ per cent. Vessels constructed with three dry-air spaces only reduced the influx of heat to 35 per cent. An ordinary mercury vacuum vessel is therefore ten times more economical for storing liquid air, apart from considerations of manipulation, than a triple annular-spaced air vessel. It has been suggested that the metallic coating of mercury does no good, because Pictet has found that all kinds of matter become transparent to heat at low temperatures. The results above mentioned dispose of this assumption, and direct experiment proves that no increase in the transparency of glass to thermal radiation is effected by cooling it to the boiling point of air.[1]

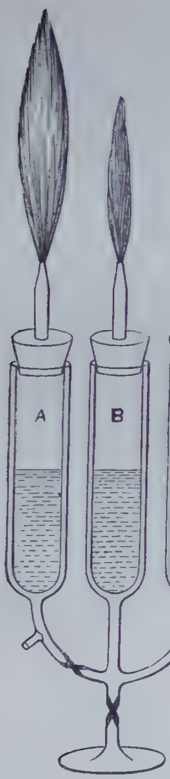
An ocular demonstration of the correctness of the above statements can easily be shown by mounting on the same stem three similar double-walled test tubes, two of which have been simultaneously exhausted and sealed off from the air pump together, while the third is left full of air. One of the vacuum test tubes is coated with silver in the interior. The apparatus is shown in fig. 1, Plate III. A has the annular space filled with air; B and C are exhausted, C being coated with silver. On filling liquid ethylene to the same height into each vessel and inserting corks with similar gas jets and igniting the escaping gas, the relative volumes of the flames is roughly proportional to the influx of heat, and resembles what is shown in the drawing. It is satisfactory to have independent corroboration of the advantages of the use of vacuum vessels, and this may be found in a paper by Prof. Kamerlingh Onnes, of Leyden, communicated to the Amsterdam Academy of Sciences, 1896, entitled "Remarks on the liquefaction of hydrogen, on thermodynamical similarity, and in the use of vacuum vessels," in which he says: "In the same degree as it becomes of more importance to effectuate adiabatic processes at very low temperatures, the importance of the vacuum vessels of Dewar will increase. It seems to me that they are the most important addition since 1883 to the appliances for low-temperature research." . . . "It is a rejoicing prospect that practical engineers will doubtless feel the want of such nonconducting mantles. For as soon as this stage is reached numbers of heads and

[1] At a meeting of the French Academy in 1895 a paper by M. Solvay, of Brussels, was read, in which my 1892 device of vacuum vessels was attributed to M. Cailletet, and tacitly accepted by him. In 1875 I had already used a highly exhaustive vessel, of similar shape to the vacuum test tube, in calorimetric experiments. See paper on "The physical constants of hydrogenium," Trans. Roy. Soc. Ed., Vol. XXVII. Even as late as April, 1896, Professor Tilden, D. Sc. F. R. S. of the Royal College of Science, in a paper entitled "L'Appareil du Dr. Hampson pour la liquéfaction de l'air et des gas," communicated to the Revue Générale des Sciences, thought proper to write as follows: "Un manchon de verre, dans lequel on a fait le vide (manchon semblable à ceux décrits par Cailletet ou Dewar)." Where did Professor Tilden find Cailletet's description of a vacuum vessel? This is not the only statement in the paper requiring correction.

hands are disposed to take over the problem from the scientific researcher."

Solid air.—As Professor Olszewski has recently alleged that air does not solidify at the lowest pressures,[1] the author's former experiments were repeated on a larger scale. If a liter of liquid air is placed in a globular silvered vacuum vessel and subjected to exhaustion, as much as half a liter of solid air can be obtained and maintained in this condition for half an hour. At first the solid is a stiff, transparent jelly, which, when examined in the magnetic field, has the liquid oxygen drawn out of it to the poles. This proves that solid air is a nitrogen jelly containing liquid oxygen. This statement was made in a paper "On the refraction and dispersion of liquid oxygen, and the absorption spectrum of liquid air" (Professors Liveing and Dewar), published in the Philosophical Magazine for September, 1895, yet Professor Olszewski, in 1896,[2] is declaring "that Professor Dewar has stated that liquid air solidifies as such, the solid product containing a slightly smaller percentage of nitrogen than is present in the atmosphere. My experiments have proved this statement to be incorrect." The Cracow professor may well have the satisfaction of correcting a statement which was never made by me. He seems also to forget that in 1893 (Proceedings Royal Institution, "Lecture on liquid air"), it is distinctly stated that "all attempts to solidify oxygen by its own evaporation have failed." Solid air can only be examined in a vacuum or in an atmosphere of hydrogen, because it instantly melts on exposure to air cooled to the temperature of its boiling point, giving rise to the liquefaction of an additional quantity of air. It is strange to see a mass of solid air melting in contact with the atmosphere, and all the time welling up like a kind of fountain. The apparatus shown in fig. 2, Plate III, is well adapted for showing the direct liquefaction of the air of a room and its solidification. A large vacuum vessel, G, is mounted on a brass stand containing another smaller vessel, B, of the same kind. By means of the two cocks, C and D, either the large vessel G or the bulb B can be connected to the air-pump circuit. Liquid oxygen is placed in A, which can, by opening the stopcock D, be cooled to —210° by exhaustion. If the stopcock C is shut and a barometric gauge is joined on at F, the dropping of the liquid air from the outside of A will go on even at as low a pressure as 4 inches of mercury; which is equivalent to saying that this apparatus would liquefy air if taken by a balloon 10 miles high. If F is now opened, giving a supply of air at atmospheric pressure, the cup B soon fills with liquid air. Unless the air supply is passed over soda lime and strong sulphuric, the liquid is always turbid from the presence of ice crystals and solid carbonic acid. Now, on shutting F and opening C the air in B is placed under exhaustion and soon solidifies to a jelly-like mass. When the vacuum is about 14 mm. then the temperature of the solid air is —232° by the platinum resistance thermometer, or —216° C. On allowing the air to enter, the solid instantly melts and more liquid air is formed.

[1] Phil. Mag., Feb., 1895. [2] See Nature, Aug. 20, p. 378.



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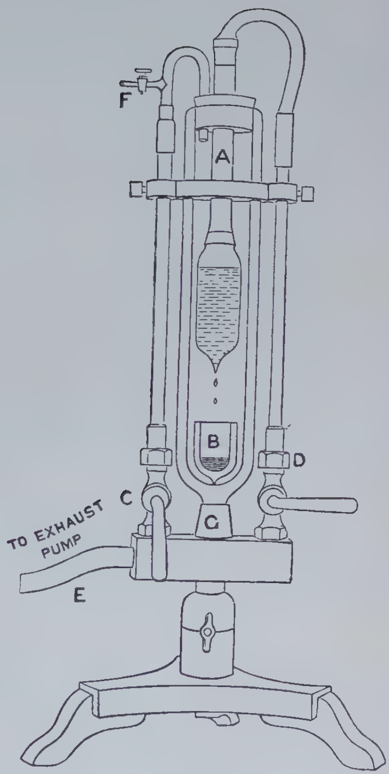


2

1. LIQUID ETHYLENE FLAME CALORIMETER.

2. LECTURE APPARATUS FOR PROJECTING THE LIQUEFACTION OF AIR AT ATMOSPHERIC PRESSURE AND ITS SOLIDIFICATION.

The same experiment may be repeated many times by simply opening and shutting the stopcocks. When the liquid air loses too much nitrogen, then it no longer solidifies. This apparatus may be used to show that when liquid air is running freely into B liquefaction is instantly arrested by allowing hydrogen to enter instead of air.

Samples of air liquefied in sealed flasks.—In a paper "On the relative behavior of chemically prepared and of atmospheric nitro gen," communicated to the Chemical Society in December, 1894, the plan of manipulating such samples was described. The arrangement shown in Plate IV, illustrates how oxygen in A under 0.21 of an atmosphere pressure, and nitrogen in B under 0.79 of an atmosphere, can be compared as to the first appearance of liquefaction in each, and finally as to their respective tensions when the temperature is as low as that of solid nitrogen. The flasks A and B have the capacity of more than a liter. Each has a manometer sealed on, and in each phosphoric anhydride is inserted to secure dryness. A large vacuum vessel, C, holds the liquid air, which is gradually lowered in temperature by boiling under exhaustion. The moment liquefaction takes place the tubes D′ D″ begin to show liquid. The tubes must be drawn fine at the end when accurate observations are being made. In the same manner two oxygen flasks were compared. One was filled with gas made from fused chlorate of potash contained in a side tube sealed onto the flask. The other was treated in the same way, only the chlorate had a little peroxide of manganese added. The former gave perfectly clear blue liquid oxygen; the latter was turbid from solid chlorine. Two flasks of dry air that had stood over phosphoric anhydride were liquefied side by side, the only difference between the samples being that one was free from carbonic acid. The one gave a liquid that was perfectly clear; the other was turbid from the 0.04 per cent of carbon dioxide.

The temperature was lowered by exhaustion until samples of liquid air from two flasks placed side by side as in Plate IV, became solid. The flasks were then sealed off for the purpose of examining the composition of the air that had not been condensed. The one sample contained oxygen, 21.19 per cent, and the other 20.7 per cent. This is an additional proof to the one previously given that, substantially, the oxygen and nitrogen in air liquefy simultaneously, even under gradually diminishing pressure, and that in these experiments all the known constituents of air are condensed together. These results finally disprove the view expressed in "A system of inorganic chemistry,"[1] by Professor Ramsay, where he says: "Air has been liquefied by cooling to —192°, but as oxygen and nitrogen have not the same boiling points, the less volatile oxygen doubtless liquefies first." My old experiments[2] showed that the substance now known as argon became solid before nitrogen, but chemical nitrogen and air nitrogen,

[1] 1891, p. 70. [2] See Proc. Chem. Soc., Dec., 1894.

with its 0.1 per cent of argon, behaved in substantially the same way on liquefaction.

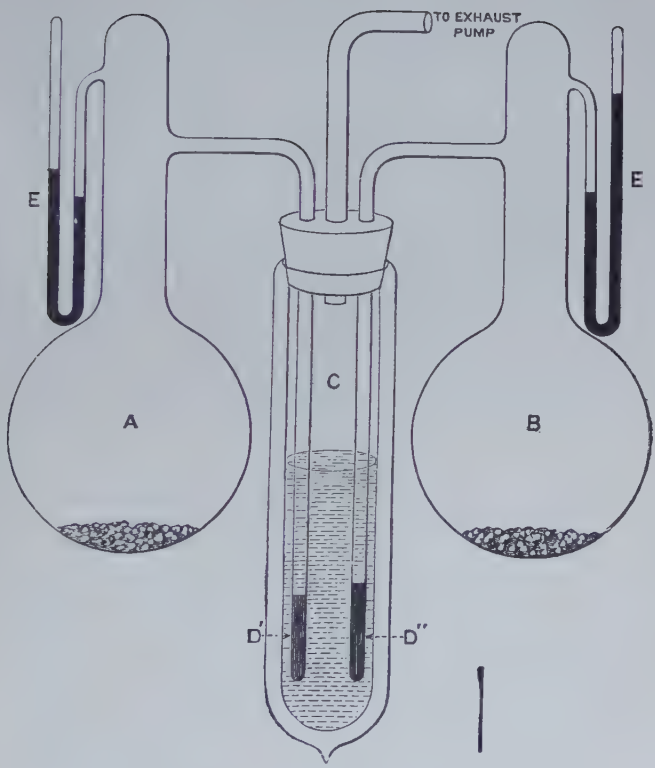
Liquid nitric oxide.—Great interest attaches to the behavior of nitric oxide at low temperatures. Professor Olszewski has examined the liquid and describes it as colorless. Samples of nitric oxide have been prepared in different ways. These have been transferred to liquefaction flasks, where they were left in contact with anhydrous potash, sulphuric acid alone, a mixture of sulphate of aniline and sulphuric acid, or phosphoric acid, for many days before use. Each of the samples, when cooled, gave a nearly white solid, melting into a blue liquid. The color is more marked at the melting point than at the boiling point. Liquid nitric oxide is not magnetic; neither is the solid phosphorescent. Color in the oxides of nitrogen evidently begins with the second oxide. Solid nitric oxide does not show any chemical action when placed in contact with liquid oxygen, provided the tube containing it is completely immersed; but if the tube full of liquid oxygen is lifted into the air, almost instantly a violent explosion takes place.

Specific gravities taken in liquid oxygen.—In a good vacuum vessel specific gravities may be taken in liquid oxygen with as great ease as in water. The shape of the vacuum vessel which works best is shown in fig. 1, Plate V. It must contain excess of mercury and be thoroughly boiled out, so that the inner vessel becomes completely coated with a mercury mirror as soon as the liquid oxygen is filled in. Instead of a mercury vacuum, the interior may be silvered and highly exhausted by a Sprengle pump. The flasks must also be thoroughly clean and free from dust, otherwise the liquid oxygen will not remain tranquil. Any superheating is prevented by inserting a long narrow piece of wood for a moment before the final weighing.

Some twenty substances were weighed in liquid oxygen,[1] and the apparent relative density of the oxygen determined. The results were then corrected, using Fizeau's values for the variation of the coefficient of expansion of the solids employed, and thereby the real density of liquid oxygen calculated. The resulting value was 1.1375, bar. 766.5, in the case of such different substances as cadmium, silver, lead, copper, silver iodide, calc-spar, rock crystal. The following table gives some of the observations:

Mean cubical coeficient of expansion between 15° C.–183° C.		Apparent density of liquid oxygen.	Real density of liquid oxygen.
Cadmium,	7986×10^{-5}	1.1188	1.1359
Lead,	7892×10^{-5}	1.1197	1.1367
Copper,	4266×10^{-5}	1.1278	1.1370
Silver,	5185×10^{-5}	1.1278	1.1385
Calc-spar,	1123×10^{-5}	1.1352	1.1376
Rock crystal,	2769×10^{-5}	1.1316	1.1376
Silver iodide,	0189×10^{-5}	1.1372	1.1376

[1] The liquid oxygen might possibly contain a small proportion of nitrogen.



PLAN OF COMPARING RELATIVE TEMPERATURES OF LIQUEFACTION AND SMALL VAPOR PRESSURES.

Direct determinations with an exhausted glass cylindrical vessel displacing about 22 c. c. gave 1.1378. Fizeau's parabolic law for the variation of the coefficient of expansion holds down to —183°. The solid which showed the greatest contraction was a block of compressed iodine; the one that contracted least being a compressed cylinder of silver iodide. Wroblewski gave the density of liquid oxygen at the boiling point as 1.168, whereas Olszewski found 1.124. The variation of density is about ± 0.0012, for 20 mm. barometric pressure. Much work requires to be done in the accurate determination of the physical constants of liquid gases.

Liquid air.—A large silver ball weighed in liquid air gave the density of the latter as 0.910, and the corresponding density of nitrogen at its boiling point 0.850. It is difficult to be quite certain that the constituents of liquid air are in the same proportion as the gaseous ones, so that further experiments must be made. Liquid air kept in a silvered vacuum vessel gradually rises in boiling point from the instant of its collection, the rate of increase during the first hour being nearly directly proportional to the time. As the increase amounted to 1° in ten minutes, the boiling point of oxygen ought to have been reached within two hours. The density of liquid air, however, does not reach that of pure oxygen even after thirty hours' storage. The large apparatus of the Royal Institution for air liquefaction can be arranged to deliver liquid air containing 49 per cent of oxygen, which gives off gas containing 20 per cent of oxygen, rising after six hours to 72.6 per cent.

Combustion in liquid oxygen.—A small ignited jet of hydrogen burns continuously below the surface of liquid oxygen, all the water produced being carried away as snow. There is a considerable amount of ozone formed, which concentrates as the liquid oxygen evaporates. In the same way graphite or diamond, when properly ignited, burns continuously on the surface of liquid oxygen, producing solid carbonic acid and generating ozone. If liquid oxygen is absorbed in wood charcoal or cotton wool and a part of the body heated to redness, combustion can start with explosive violence.

Gas jets containing liquid.—The experiments of Joule and Thomson and Regnault on the temperature of gas jets issuing under low pressures are well known. The following observations refer to the pressure required to produce a lowering of temperature sufficient to yield liquid in the gas jet.

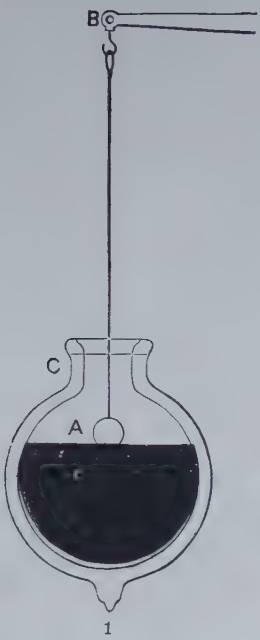
The apparatus used in the study of highly compressed gas jets is represented in fig. 2, Plate V, where C is a vacuum tube which holds a coil of pipe about 5 mm. in diameter surrounded with carbon dioxide or liquid air for cooling the gas before expansion, and A is a small hole in the silver or copper tube about $\frac{1}{5}$ mm. in diameter, which takes the place of a stopcock. When carbon dioxide gas at a pressure of 30 or 40 atmospheres is expanded through such an apperture, liquid can be seen

where the jet impinges on the wall of the vacuum tube, along with a considerable amount of solid. If oxygen gas escapes from the small hole at the pressure of 100 atmospheres, having been cooled previously to —79° in the vessel C, a liquid jet is just visible. It is interesting to note, in passing, that Pictet could get no liquid oxygen jet below 270 atmospheres. This was due to his stopcock being massive and outside the refrigerator. If the oxygen is replaced by air, no liquid jet can be seen until the pressure is 180 atmospheres, but on raising the pressure to 300 atmospheres the liquid air collected well from the simple nozzle. If the carbon dioxide is cooled by exhaustion (to about 1-inch pressure) or —115°, then liquid air can easily be collected in the small vacuum vessel D, or if the air pressure is raised above 200 atmospheres, keeping the cooling at —79° as before.[1] The chief difficulty is in collecting the liquid, owing to the rapid current of gas. The amount of liquid in the gas jet is small, and its collection is greatly facilitated by directing the spray on a part of the metallic tube above the little hole, or by increasing the resistance to the escaping gas by placing some few turns of the tube, like B in the figure, in the upper portion of the vacuum tube, or generally by pushing in more tube in any form. A vacuum vessel shaped like an egg-glass also works well. This practically economizes the cool gas, which is escaping to reduce the temperature of the gas before expansion, or, in other words, it is the cold regenerative principle. Coleman pointed out long ago that his air machine could be adapted to deliver air at as low a temperature as has yet been produced in physical research. Both Solvay and Linde have taken patents for the production of liquid air by the application of cold regeneration, but the latter has the credit of having succeeded in constructing an industrial apparatus that is lowered in temperature to —40°, or to the critical point of air, in about fifteen hours, and from which liquid air containing 70 per cent oxygen is collected after that time.

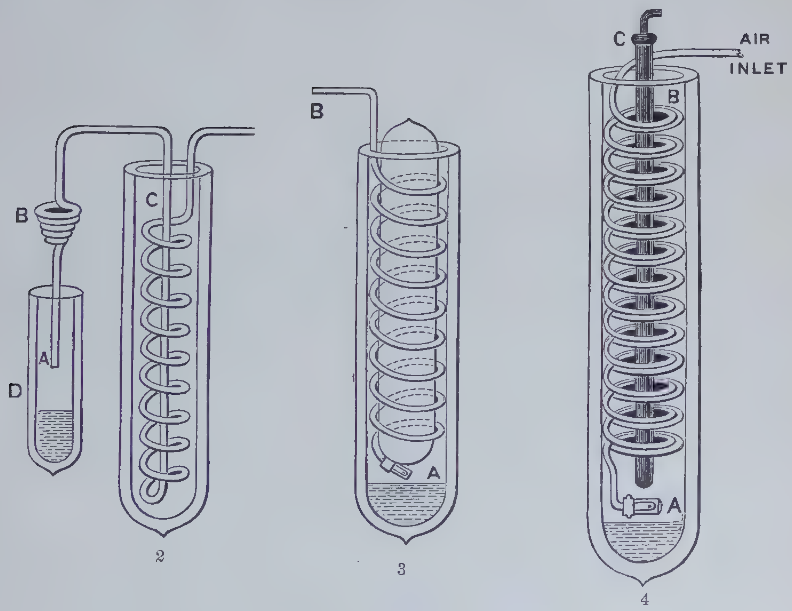
For better isolation, the pipe can be rolled between two vacuum tubes, the outer one being about 9 inches long and 1½ inch diameter, as shown in fig. 3, Plate V. The aperture in the metal pipe has a little piece of glass tube over it, which helps the collection of the liquid. With such a simple apparatus, and an air supply at 200 atmospheres with no previous cooling, liquid air begins to collect in about five minutes, but the liquid jet can be seen in between two and three minutes. It is not advisable to work below 100 atmospheres.

In fig. 4, Plate V, the metallic tube in the vacuum vessel is placed in horizontal rings, leaving a central tube to allow the glass tube C to pass, which is used to cool bodies or examine gases under compression. The inner tube can be filled for an inch with liquid air under a pressure

[1] The liquefaction is taking place in this condition at 1¼ times the critical temperature. Hydrogen similarly expanded at the melting point of air (—211° C.) behaves exactly in the same way.



1. SPECIFIC GRAVITY VACUUM GLOBE.



2, 3, 4. DIFFERENT ARRANGEMENTS OF REGENERATING COILS.

of 60 atmospheres in about three minutes. Generally, in the experiments, about ½ to 4 cubic feet of air passes through the different sized needle holes per minute when the pressure is about 200 atmospheres. As the small hole is apt to get stopped, for general working it is better to use a needle stopcock, worked from the outside by a screw passing through the middle of the coil of pipe.

In testing the individual coils as to the amount of air passed per minute under different pressures, the arrangement of apparatus shown in Plate VI was used.

A is a bottle of compressed air, to which the copper pipe B is attached. This coiled pipe first passes through the vessel C, containing water, in order to equalize the temperature, and then through the cork D into the glass vacuum vessel E, when it is led by a large number of convolutions to the bottom, terminating in a minute pin-hole valve F. The released air passes from F right up through the coils and out of the vent by the copper tube G, which in its turn passes through a vessel H, similar in its object to C, and is then conducted to a measuring meter J.

The following table gives the results of a series of experiments made on one coil as to the rate of discharge of air at different pressures:

Pressure in atmospheres.	Cubic feet per minute measured under atmosphere at 15°.
55	0.22
105	0.42
155	0.63
98	0.79
210	0.84
250	1.00
287	1.15
290	1.18

The results show that the rate of air discharge through a fine aperture is directly proportionate to the pressure, or the velocity with which the gas on the high-pressure side enters the orifice, is independent of the density. Actual measurements of the size of the needle hole resulted in proving that the real velocity of the air entering the aperture on the high-pressure side was about 500 feet per second. In all these experiments the temperature of the coil was not allowed to get so low as to produce any visible trace of condensation in the air jet. Just before liquefaction the rate of discharge of air through the same aperture may be doubled, the pressure remaining steady, owing to change in the viscosity of the gas and other actions taking place at low temperatures. The above measurements can only be regarded as representing the general working of such regenerating coils.

A double coil of pipe has advantages in the conduct of some experi-

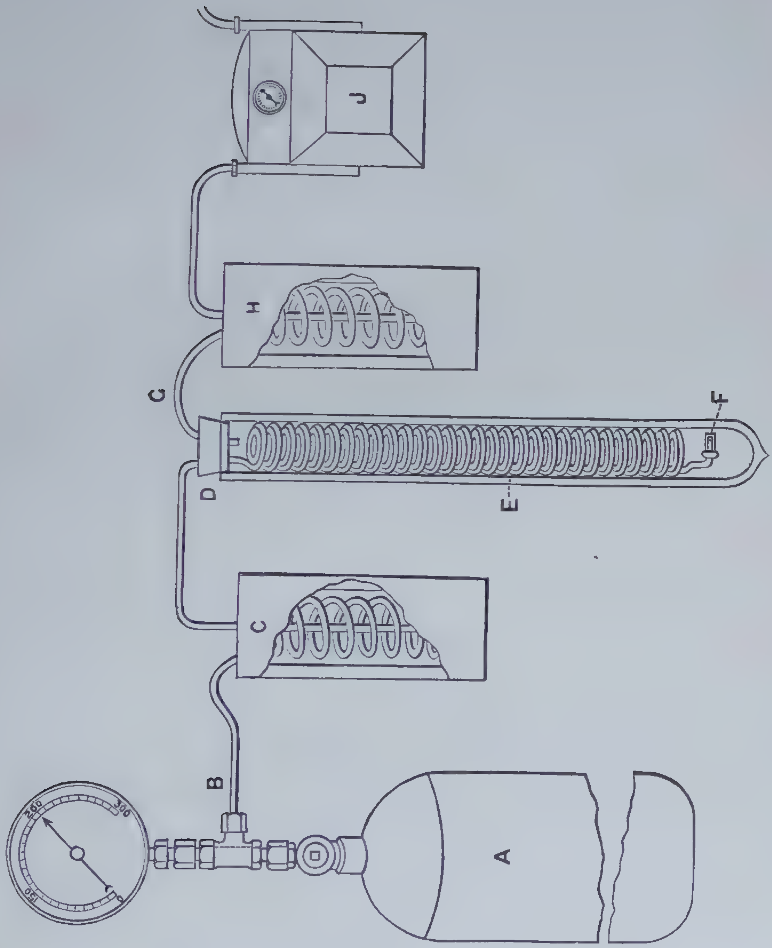
ments. The efficiency is small, not exceeding the liquefaction of 2 to 5 per cent of the air passing, but it is a quick method of reaching low temperatures, and easy to use for cooling tubes and collecting a few hundred c. c. of liquid air, especially if the compressed air is delivered at the temperature of —79° before expansion. With larger vacuum vessels and larger regenerating coils, no doubt the yield of liquor could be increased. The liquid air resulting from the use of this form of apparatus contains about 50 per cent of oxygen. If the air is cooled with solid carbonic acid previous to its reaching the vacuum tube coil of pipe, the only change is to reduce the percentage of oxygen to 40. Successive samples of liquid taken during the working had nearly the same composition. If the arrangement shown in Plate VII is used, with silver tube, about $\frac{1}{16}$ inch bore, and a foot or two coiled in upper part of the vacuum vessel, liquid air containing 25 per cent of oxygen is obtained. On the other hand, the percentage of oxygen can be increased by a slight change in the mode of working.

In the above experiments air is taken at the ordinary temperature, which is a little above twice its critical temperature, and is partially transformed in a period of time which, in my experiments, has never exceeded ten minutes, simply and expeditiously into the liquid state at its boiling point, —194°, or a fall of more than 200° has been effected in this short period of time.

Experiments on hydrogen.—Wroblewski made the first conclusive experiments on the liquefaction of hydrogen in January, 1884. He found that the gas cooled in a tube to the boiling point of oxygen, and expanded quickly from 100 to 1 atmospheres, showed the same appearance of sudden ebullition as Cailletet had seen in his early oxygen experiments. No sooner had the announcement been made than Olszewski confirmed the result by expanding hydrogen from 190 atmospheres previously cooled with oxygen and nitrogen boiling in vacuo. Olszewski declared in 1884 that he saw colorless drops, and by partial expansion to 40 atmospheres the liquid hydrogen was seen by him running down the tube. Wroblewski could not confirm these results, his hydrogen being always what he called a "liquide dynamique." He proposed to get "static" liquid hydrogen by the use of hydrogen gas as a cooling agent. Professor Ramsay, in his System of Inorganic Chemistry, published long after the early experiments of Pictet, Cailletet, Wroblewski, and Olszewski on the liquefaction of hydrogen had been made, sums up the position of the hydrogen question in 1891 as follows (p. 28):

> It has never been condensed to the solid or liquid states. Cailletet, and also Pictet, who claim to have condensed it by cooling it to a very low temperature and at the same time strongly compressing it, had in their hands impure gas. Its critical temperature, above which it can not appear as liquid, is probably not above —230°.

It has to be remembered that 7 per cent of air by volume in hydrogen means about 50 per cent by weight of the mixed gases. Even 1



PLAN OF APPARATUS USED IN MEASURING RATE OF PASSAGE OF GAS AT HIGH PRESSURE THROUGH A SMALL PIN HOLE.

per cent by volume in hydrogen is equivalent to some 13 per cent by weight.

The following table gives the theoretical temperatures reached for an instant during the adiabatic expansion of hydrogen under different conditions:

Initial pressure (atmospheres).	Initial temperature.	Theoretical final temperature (absolute).
	°	°
500 (Pictet)	—130	25
300 (Cailletet)	0	52
100 (Wroblewski)	—184	24
180 (Olszewski)	—210	14
100	—200	19.5
200	—200	15.7
500	—200	12.7

The calculations show that little is gained by the use of high pressures. The important inference to be drawn from the figures is to start with as low a temperature as possible.

From 1884 until his death, in the year 1888, Wroblewski devoted his time to a laborious research on the isothermals of hydrogen at low temperatures. The data thus arrived at enabled him, by the use of Van der Waal's formulæ, to define the critical constants of hydrogen, its boiling point, density, etc., and the subsequent experiments of Olszewski have simply confirmed the general accuracy of Wroblewski's results. Wroblewski's critical constants of hydrogen are given in the following table:

Critical temperature	degrees	—240
Critical pressure	atmospheres	13.3
Critical density		.027
Boiling point	degrees	—250
Density at boiling point[1]		.063

In a paper published in the Philosophical Magazine, September, 1884, "On the liquefaction of oxygen and the critical volumes of fluids," the suggestion was made that the critical pressure of hydrogen was wrong, and that instead of being 99 atmospheres, as deduced by Sarrau from Amagat's isothermals, the gas had probably an abnormally low value for this constant. This view was substantially confirmed by Wroblewski finding a critical pressure of 13.3 atmospheres, or about one fourth that of oxygen. The Chemical News (September 7, 1894) contains an account of the stage the author's hydrogen experiments had reached at that date. The object was to collect liquid hydrogen at its boiling point in an open vacuum vessel, which is a much more difficut problem than seeing the liquid in a glass tube under pressure and at a higher temper-

[1] It is probable that the real density of boiling liquid hydrogen may lie between 0.12 and 0.18.

ature. In order to raise the critical point of hydrogen to about −200°, from 2 to 5 per cent of nitrogen or air was mixed with it. This is simply making an artificial gas containing a large proportion of hydrogen, which is capable of liquefaction by the use of liquid air. The results are summed up in the following extract from the paper:

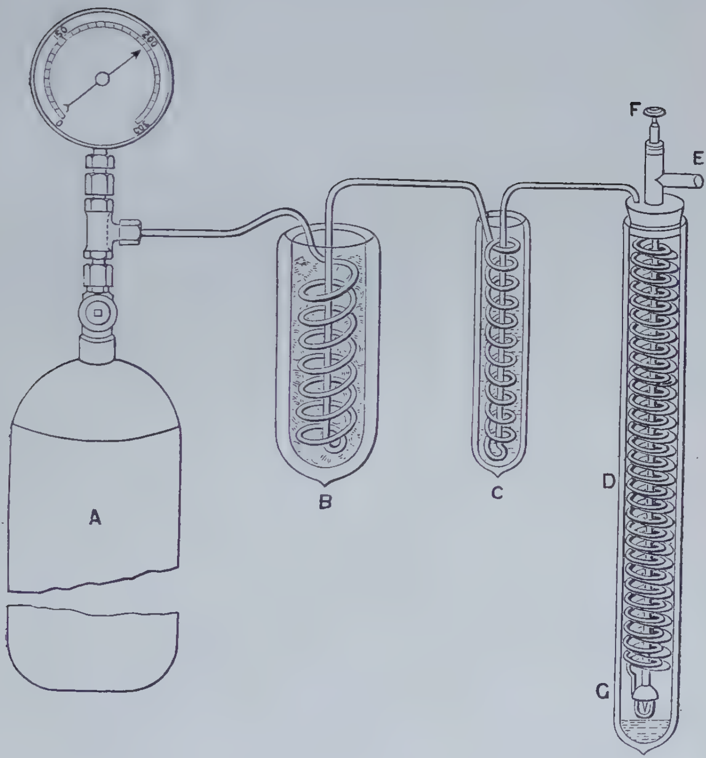
One thing can, however, be proved by the use of the gaseous mixture of hydrogen and nitrogen, viz, that by subjecting it to a high compression at a temperature of —200°, and expanding the resulting liquid into air, a much lower temperature than anything that has been recorded up to the present time can be reached. This is proved by the fact that such a mixed gas gives, under the conditions, a paste or jelly of solid nitrogen, evidently giving off hydrogen because the gas coming off burns fiercely. Even when hydrogen containing only some 2 to 5 per cent of air is similarly treated the result is a white, solid matter (solid air) along with a clear liquid of low density, which is so exceedingly volatile that no known device for collecting has been successful.[1]

In Professor Olszewski's paper "On the liquefaction of gas,"[2] after detailing the results of his hydrogen experiments, he says: "The reason for which it has not hitherto been possible to liquefy hydrogen in a static state is, that there exists no gas having a density between that of hydrogen and nitrogen, and which might be, for instance, 7—10 (H = 1). Such a gas would be liquefied by means of liquid oxygen or air as cooling agent, and afterwards used as a recognized menstruum in the liquefaction of hydrogen. Science will probably have to wait a very long time before this suggestion of how to get "static" liquid hydrogen is realized. The proposal Wroblewski made in 1884, of using the expansion of hydrogen as a cooling agent to effect the change of state, is far more direct and practicable.

Liquid hydrogen jet and solid hydrogen.—Hydrogen cooled to —194° (80° abst. *t.*), the boiling point of air, is still at a temperature which is two and a half times its critical temperature, and its direct liquefaction at this point would be comparable to that of air taken at 60°, and liquefied by the apparatus just described. In other words, it is more difficult to liquefy hydrogen (assuming it to be supplied at the temperature of boiling air) than it is to produce liquid air starting from the ordinary atmospheric conditions. Now, air supplied at such a high temperature greatly increases the difficulty and the time required for liquefaction. Still it can be done, even with the air supply at 100°, in the course of seven minutes, and this is the best proof that hydrogen, if placed under really analogous conditions, namely, at —194°, must also liquefy with the same form of apparatus. It is almost needless to say that hydrogen under high compression at the temperature of 15° C. passed through such a regenerating coil, produced no lowering of temperature. Hydrogen cooled to —200° was forced through a fine

[1] The compressed gas mixture at above —210° was expanded into a large cooled vacuum vessel.

[2] Phil. Mag., 1895.



APPARATUS USED IN THE PRODUCTION OF THE LIQUID HYDROGEN JET.

nozzle under 140 atmospheres pressure, and yet no liquid jet could be seen. If the hydrogen contained a few per cent of oxygen the gas jet was visible, and the liquid collected, which was chiefly oxygen, contained hydrogen in solution. the gas given off for some time being explosive.

If, however, hydrogen, cooled by a bath of boiling air, is allowed to expand at 200 atmospheres over a regenerative coil previously cooled to the same temperature and similar in construction to that shown in Plate VII,[1] a liquid jet can be seen after the circulation has continued for a few minutes, along with a liquid which is in rapid rotation in the lower part of the vacuum vessel. The liquid did not accumlate, owing to its low specific gravity and the rapid current of gas. These difficulties will be overcome by the use of a differently shaped vacuum vessel and by better isolation. That liquid hydrogen can be collected and manipulated in vacuum vessels of proper construction can not be doubted. The liquid jet can be used in the meantime (until special apparatus is completed for its collection) as a cooling agent—like the spray of liquid air obtained under similar circumstances—and this being practicable, the only difficulty is one of expense. In order to test, in the first instance, what the hydrogen jet could do in the production of lower temperatures, liquid air and oxygen were placed in the lower part of the vacuum tube, just covering the jet. The result was that in a few minutes about 50 c. c. of the respective liquids were transformed into hard, white solids resembling avalanche snow, quite different in appearance from the jelly-like mass of solid air got by the use of the air pump. The solid oxygen had a pale, bluish color, showing by reflection all the absorption bands of the liquid. The temperatures reached and other matters will be dealt with in a separate communication. When the hydrogen jet was produced under the surface of liquid air, the upper part of the fluid seemed to become specifically lighter, as a well-marked line of separation could be seen traveling downward. This appearance is no doubt due in part to the greater volatility of the nitrogen and the considerable difference in density between liquid oxygen and nitrogen. In a short time solid pieces of air floated about, and the liquid subsequently falling below the level of the jet, hydrogen now issued into a gaseous atmosphere containing air, which froze solid all round the jet. There is no reason why a spray of liquid hydrogen at its boiling point in an open vacuum vessel should not be used as a cooling agent, in order to study the properties of matter at some 20° or 30° above the absolute zero.

Fluorine.—This is the only widely distributed element that has not been liquefied. Some years ago Wallach and Hensler pointed out that an examination of the boiling points of substituted halogen organic

[1] In the figure, A represents one of the hydrogen cylindres; B and C, vacuum vessels containing carbonic acid under exhaustion and liquid air, respectively; D, regenerating coil; G, pin-hole nozzle; F, valve.

compounds led to the conclusion that although the atomic weight of fluorine is nineteen times that of hydrogen, yet it must in the free state approach hydrogen in volatility. This view is confirmed by the atomic refraction which Gladstone showed was 0.8 that of hydrogen, and from which we may infer that the critical pressure of fluorine is relatively small, like hydrogen.[1] If the chemical energy of fluorine at low temperatures is abolished, like that of other active substances, then some kind of glass or other transparent material could be employed in the form of a tube, and its liquefaction achieved by the use of hydrogen as a cooling agent. In any case a platinum vessel could be arranged to test whether fluorine resists being liquefied at the temperature of solid air, and this simple experiment, even if the result was negative, would be of some importance.

During the conduct of these investigations, I have gratefully to acknowledge the able assistance rendered by Mr. Robert Lennox, my chief assistant. Valuable help has also been given by Mr. J. W. Heath.

[1] On the other hand, the exceptionally small refractivity value observed by Lord Rayleigh in the case of helium shows that the critical pressure of this body is proportionately high. It would therefore be more difficult to liquefy than a substance having about the same critical temperature, but possessing a lower critical pressure, like hydrogen.

METEOROLOGICAL OBSERVATORIES.[1]

By Richard Inwards, F. R. A. S.,
President of the Royal Meteorological Society, London.

As meteorology is essentially a science of observation, the present discourse will be devoted to giving some scant and scattered details of a few of the different organized arrangements in various parts of the world, for carrying on researches into the constitution of the atmosphere, and the effects of changes in its condition from day to day. The subject of observatories is a wide one, and I shall not attempt to condense the account of the whole world's work in this direction into the talk of one short hour. There is a map which has been printed by Mr. Scott to illustrate his address[2] from this chair in 1885 on the condition of climatological observations over the globe, which is instructive as showing at one glance the points on the world's surface from which the weather was systematically observed ten years ago. The map is shown to be dotted over in nearly every quarter, but, as might be expected, the dots are closer together near the great centers of civilization, while vast portions of the earth's surface, in desert plains and among mountains, on the oceans and in the polar regions, are practically barren in this respect, and the movements of the atmosphere there remain almost unstudied and unrecorded.

ANCIENT OBSERVATORIES.

In early savage times there is no doubt that keen observations, and a system of weather guessing, represented the whole science of meteorology, and any prominent rock or tree served the purposes of an observatory from whence the early hunters, fishers, or sailors anxiously scanned the horizon for signs of the weather to come. Such a primitive arrangement in New Guinea I now show you photographed, and you will see that it is merely a dwelling in a tree, on the top of which may be seen the anxious inhabitants peering into space, their sight,

[1] An address delivered to the Royal Meteorological Society, London, January 15, 1896. Printed in Quarterly Journal of the Royal Meteorological Society, Vol. XXII, No. 98, April, 1896, pp. 81–98. The illustrations accompanying the article are omitted in this reprint.

[2] Quarterly Journal, Vol. XI, pl. 4.

no doubt, sharpened by the consideration of the chances which determine the date of their next meal of fish or game.

NILOMETER.

It is a long step from the lookout tree of the savage to the more scientific efforts of the Egyptians and Greeks, who certainly had systematic observations made in special buildings, and which structures might with truth be called observatories, though not supplied like ours with means and methods of a high and complicated order. The great pyramid has been claimed for such an observatory, and some writers suppose that from an opening in its side the learned priests watched the transits of the stars and the rising of the constellations to determine the march of the various seasons suitable for agriculture or for the irrigation of their people's lands. Then they had Nilometers at various points in the course of their river, by which they took accurate note of its height at any season. There were many of these structures, perhaps the oldest being that at Memphis. There is one on the island of Rhoda, near Cairo, which remains in full operation to this day, having been more than eleven centuries in existence; and it may be claimed as the oldest flood gauge—and therefore rain gauge—in the world. The older Nilometers are mentioned by Herodotus, Strabo, and others, while our own Shakespeare thus speaks of this matter in the play of Antony and Cleopatra:

> They take the flow o' the Nile
> By certain scales i' the pyramid; they know,
> By the height, the lowness, or the mean, if dearth,
> Or foison follow. The higher Nilus swells,
> The more it promises.[1]

Although Shakespeare was probably mistaken in placing a Nilometer in a pyramid, it is very wonderful that he should have known of it at all.

Messrs. Symons and Chatterton, in their paper on floods[2] last year, deplored the absence of systematic flood marks on the Thames and Severn, and I commend the authorities to the ancient Egyptians for an example.

TEMPLE OF THE WINDS, ATHENS.

The Greeks inherited and sifted out all the wisdom of Egypt, and it therefore does not surprise us to find in the very heart of ancient Athens, and almost under the shadow of the Acropolis, a building which may be claimed as an archetype of observatories, and which yet remains standing in the modern city.

I mean the little marble octagon tower called the Temple of the Winds. The eight sides of this temple are built to face the eight principal winds, and on each side is sculptured a human figure in high relief, and

[1] Antony and Cleopatra, Act 2, Scene VII.
[2] Quarterly Journal, Vol. XXI, page 189.

which represents, as far as a figure can, the character and qualities of the particular wind which it faces.

For instance, the north wind, which is cold, fierce, and stormy, is represented by the sculptured figure of a man warmly clad and blowing fiercely on a trumpet made out of a seashell.

The northeast wind, which brought, and still brings, to the Athenians cold, snow, and hail, was figured by an old man with a severe countenance, and who is rattling sling stones in a shield, a good way of expressing emblematically the noise and power of a hailstorm.

The east wind, which brought, and still brings, to the Greeks a gentle rain, favorable to vegetation, is expressed by the image of a young man with flowing hair and open countenance, having his looped up mantle filled with fruit, honeycomb, and corn.

Zephyros, the west wind, was indicated by the figure of a slightly clad and beautiful youth with his lap full of flowers. And so with the other winds all round the compass; each has its qualities fixed in stone by its appropriate sculptured figure, and we have here a most interesting evidence that the climate of Greece has not materially changed, at any rate in respect of winds, after the lapse of about twenty centuries.

The tower had a vane on the top made to represent a Triton, who turned with the wind and waved a brazen rod over the figure which portrayed it. This tower is described by Vitruvius and other ancient authors, some of whom call it a horologium, and they suppose it contained a water clock, or clepsydra, to mark the hours during the night and in cloudy weather when the fine sundials with which the building is decorated would not be in operation. This seems at first confirmed by certain pools and gutters which have been found in the floor, and which it would have pleased me very much to claim for some rainfall or evaporation recording purposes.

The names of the various winds are written upon the faces of the building in good Greek letters, so that all might read whether Boreas or Notus, Apeliotes or Sciron—there is a sound and fury in the very names—were bringing to them comfort or disaster, as the case might be.[1]

For those who could not read there remained the emblematic signs which told them the story in stone, and which served like fossils in a rock to carry down the tale even to our own days.

The principal use of the temple was probably in order that the devout might offer prayers and gifts in view of obtaining the wind and weather they most required for nautical and agricultural reasons. It must be confessed that the building was rather badly situated for a mere observatory.

OBSERVATORIES.

About modern observatories it is my intention to give a few descriptive particulars on, first, national observatories, of which our own at

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[1] Stuart and Revett, *Antiquities of Athens*, vol. 1, where will be found numerous illustrations of the tower and its ornamentation.

Greenwich is taken as a type; second, observatories in high places; and, third, a few notes on private observing stations, with perhaps some suggestions as to what may still remain to be done.

ROYAL OBSERVATORY, GREENWICH.

A first-order station is one at which continuous observations are taken with self-recording instruments; and I will take you, for an example, to the Royal Observatory at Greenwich, where, by the courtesy of the astronomer-royal, and with the kind help of our past president, Mr. W. Ellis, F. R. S., and Mr. Nash, the present superintendent of the magnetical and meteorological department, I have been able to collect a little information. This, although it is not by any means new to many of our fellows, may interest others who may not have had the opportunity of visiting the observatory.

On entering the building, after passing the various establishments devoted to astronomy and horology, we find the meteorological observatory snugly placed among the other edifices, and one's first notion is that the situation is much too confined. But it is to be remembered that most of the surrounding buildings have been erected since the establishment of the meteorological department, and that owing to the formation of the hill and the small space at disposal, some crowding became inevitable. There is room to hope that this will be remedied some day by removing the magnetical and meteorological part to some more commanding site.

The building containing the principal meteorological instruments is of wood, and of only one story in height. On account of the delicate magnets below in an underground apartment, there is no iron used in the structure, the place of nails being supplied by pegs of bamboo, while the stoves, pipes, and locks are all of copper or brass.

The building is in the form of a cross and contains several rooms; one is used as a computing room, and in another, larger, is placed the standard barometer and the electrometer. Of the magnets underneath we will speak more anon. We shall first consider the outdoor instruments and imagine ourselves personally conducted to take a rapid view of what is going on in the observatory.

We note first the four thermometers which are sunk in the earth in order to take the temperature at different depths. No. 1 is at a depth of 24 French feet below the surface of the soil. The long and fragile stem of this thermometer was successfully placed in a deep hole in the gravel soil and packed up with sand, adding successfully the 12-foot, 6-foot, and 3-foot thermometers. French feet were used, in order that the results might compare with continental observations. During the first two years, 1847 and 1848, the thermometers were read every two hours; but the diurnal variations were found to be very small, and the readings have since been taken only once daily—at noon. The observations have been discussed by Professor Everett and others. As might

be expected, variations of the deepest thermometer are much less than those of the thermometer nearest the surface, and also follow the surface variations by a much longer interval. The depth of the longest thermometer is not sufficient to give any valuable results as to the increase of the temperature of the earth with depth; it is the comparison of the changes of the three thermometers with those of the air thermometer that is the valuable point.

We then approach the two stands, or screens, carrying thermometers employed for taking the temperature of the air, and we look with some respect on the central dry bulb thermometer—which is the standard thermometer for Greenwich temperature. It is placed with the standard wet bulb on the older form of open stand set up in the time of Sir George Airy and Mr. James Glaisher, and used in its present form, with some slight modifications, ever since the commencement of observations in the year 1841. It is commonly known as the "Glaisher stand," and it is so contrived that it can be turned round on its vertical axis, and so always be kept with its back to the sun, to secure a proper shade for the instruments. The other screen, set up in the year 1887, and which is of the form familiar to most of you, is known as the "Stevenson screen," and is of the pattern now used by the observers of our society. Both screens carry, in addition to the dry and wet bulb thermometers, ordinary self-registering maximum and minimum thermometers for eye observation.

We come to the shed under which is placed the apparatus for photographic registration of the dry and wet bulb thermometers first set up in the year 1848. Here, in a light-tight box, are the two thermometers so ingeniously arranged that their indications are continuously photographed on a sheet of sensitive paper fixed to an upright drum, which is slowly carried round by clockwork, so as to bring successively fresh surfaces under the beam of light which passes through the clear glass of each thermometer tube, while it is of course impeded by the opaque columns of mercury, so that when the images are duly brought out there appear on the sensitive paper two broad traces, each bounded below by a horizontal wavy line corresponding to the height of the mercury in the two tubes.

The register of the wet bulb stands immediately below that of the dry bulb. The light is automatically interrupted for a short time at every hour, producing on the developed sheet thin white columns, each for some definite hour, so that any change of temperature may be known, as well as the exact time at which it occurs. The readings of these thermometers are reduced by comparison with those of the standard dry and wet bulbs on the Glaisher or revolving stand.

If there were time, many interesting points could be mentioned, such as the extremely rapid fall of temperature that will at times take place on the occasion of sudden changes of wind, notably in squalls. Again, in frost, it is interesting to remark how, as the temperature passes

below the freezing point, the wet-bulb record will show a fall of a degree or two below the freezing point, and come back to it with a sudden leap when the wetted bulb has acquired a coating of ice, after which the record again begins to show the true variations due to evaporation from the frozen surface.

Here there are the solar and grass radiation thermometers for measuring the solar and the night radiation to the sky, and an ozone box for registering the amount of that form of oxygen in the air, notably very little in amount in the neighborhood of a great city. Observations of the water of the river Thames were made for a great many years, the results being included in the Greenwich annual volumes. In late years these were made at Deptford, but the series came to an end in 1891. It seems a pity that some other points in the neighborhood can not be found for continuing such observations.

There are various rain gauges placed on the ground near the thermometer screens, one on the top of the photographic thermometer shed, one on the top of the magnetic house, one on the roof of the old building fronting the park, and two at the Osler anemometer, one of these being self-recording. These two latter are 50 feet above the ground, and record only about three-fifths of the amount registered on the surface of the ground below. The self-recording rain gauge acts as follows: The rain is received in a vessel suspended by spiral springs. As the vessel becomes heavier it sinks with greater or less rapidity, according to the rate of the fall of rain. By means of a cord passing therefrom, over a pulley to a pencil, this rate of fall is recorded on a sheet of paper driven by clockwork. When 0.25 inch has been collected, the vessel automatically empties itself, the pencil returns to zero and begins again to record. The amount of rain falling during any given interval of time is readily ascertained.

With regard to the barometer, eye readings of the standard barometer are taken, and the variations of pressure are registered by photography.

The standard barometer is a plain-looking instrument, of Fortin pattern, made by Newman, and the tube has a bore of 0.565 inch. It is fitted with lamps and ground-glass screens to assist the readings. In the year 1877 a very elaborate comparison was made by the late Mr. Whipple between this barometer and the Kew standard barometer, with the result that the difference between the two was found not to exceed .001 inch, corresponding to a difference of only about 1 foot of level, or to that caused by a few grains of impurity in the mercury—one much less than the usual difference of reading as made by any two observers. For photographic registration a siphon barometer by a simple and effective plan, acting from a float in the shorter leg, is made to raise and depress a slotted screen, so that by a clockwork and photographic arrangement, similar in principle to that already described for the thermometers, a permanent pressure curve is con-

tinuously recorded. The slotted screen is carried by a lever of such length that the scale on the paper becomes magnified to rather more than four times the natural scale. This enables the finer oscillations, as in thunderstorms, to be better studied, and I may mention that this barometer, in common with all other self-recording barometers throughout the world, distinctly recorded in 1883 the passage of the air wave caused when Krakatoa, an island on the other side of the globe, was rent in two by a volcanic eruption.

On the top of the magnetic building we find the sunshine recorder, of the Campbell-Stokes pattern, burning, by means of a lens, a trace on a card in the usual way. Daily records of sunshine have been maintained at Greenwich since the year 1876. Near the sunshine instrument is a small, open, but well-protected thermometer screen carrying a dry bulb and maximum and minimum thermometers, for the purpose of comparing the results at this altitude—20 feet from the ground—with the results of the standard thermometer at 4 feet above the soil.

On the top of the observatory tower, which has formed a landmark since the time of Charles II, is found the Osler anemometer, for recording the direction and pressure of the wind and the amount of the rainfall. The latter we have described in speaking of the rain gauges generally. It is interesting to enter the little turret in which is the recording table carrying forward a sheet of paper moved by clockwork, and to watch the ever-moving pencils writing down at each moment the direction and force of the wind, whether it is a mere breeze or a fierce gale: a zephyr or a hurricane. The time scale usually employed is about half an inch to an hour, but an arrangement now exists by which, on a gale of wind springing up, the scale can be at once increased to twenty-four times this amount, thus giving much more minute information in regard to the variations of direction and pressure at such times. This anemometer has been at work since the year 1841. At a later date a Robinson anemometer, for registration of wind velocity, was added. It sometimes happens that the wind force is registered in an unpleasant way at Greenwich, as elsewhere, by accident, and I show you a picture of the shutter of the observatory dome which was brought down by a gale on December 22, 1894. The pressure of the wind measured at the time was 27½ pounds per square foot, and the observer inside the building narrowly escaped being struck by the suddenly released counterweight used to balance the shutter. Mr. Nash has favored me with these particulars.

We should refer to the matter of the registration of atmospheric electricity. For this the electrometer is employed, as designed by Lord Kelvin (perhaps better known as Sir William Thompson). It is placed in the principal room of the magnetic building, and consists of a carefully insulated cistern, which is in communication with the electrometer, and from which, by means of a pipe passing out into the open

air, a small jet of water is projected into the atmosphere. The electric potential of this point is thus communicated to the electrometer and recorded by a photographic arrangement on a revolving cylinder. In fine weather the electricity is usually positive in the air as compared with the earth, but in rainy weather, or in thunderstorms, rapid variations from positive to negative and back again are experienced.

Going now to the basement of the building we find the apparatus devoted to the registration of the delicate movements of magnets, made of hardened steel and delicately suspended by long silk filaments or moving on fine knife edges. Each magnet carries a small mirror so arranged as to reflect a spot of light from a lamp on to a piece of sensitive paper placed on a cylinder turned round by clockwork, so that every variation or tremor of the magnets is recorded by a corresponding varying line on the moving paper, making waves of more or less steepness thereon, according to the amount of movement.

When there is no movement or disturbance the line is straight, but this is not the usual state of things. It is scarcely necessary to remind you that any vibration, as from an earthquake shock, may also disturb the magnets mechanically, but earthquakes are rare in this country and it has not been thought necessary to set up special apparatus more particularly designed for the registration of such phenomena. On February 23, 1887, I find from the Astronomer-Royal's Report the vibration caused by an earthquake as far distant as the south of France caused a disturbance of the magnet corresponding to 20′ of arc in declination and 0.004 of horizontal force, being one two hundred and fiftieth of the whole horizontal force.

There is also the earth current apparatus for registration of the galvanic currents, that to a lesser or greater extent are always present in the earth. Two wires, each several miles in length, and both having earth plates at the two ends of the line, are placed in communication with galvanometers, one to each circuit, each galvanometer carrying a mirror for photographic registration of the variation of each current force on one cylinder placed between the two galvanometers. Since the end of the year 1890 these records have been greatly disturbed during the day by the trains running on the City and South London Electric Railway, although the nearest earth plate of the system is distant some 2½ miles from the railway.

As a concluding remark we may mention that the time scales of all the records throughout the observatory, both magnetical and meteorological, are, with one exception, identical in length, which much facilitates any collation of the various registers. The one unavoidable exception is the sunshine record, which has a somewhat more extended scale. Those similar in length number in all thirteen.

I have given these somewhat minute particulars of the work done at Greenwich to serve as an example of that which goes on at all observatories of the first order throughout the world, varying a little under

special circumstances, but in principle the same, though not always comprising so many subjects of research as pursued in our own Royal Observatory.

It must not, however, be imagined that I have enumerated all the various researches now going on there—work which is forming a firm foundation for the wider meteorology of the future.

KEW OBSERVATORY.

Greenwich is, however, not the only observatory in the vicinity of London. The other is the establishment of the Kew Observatory, which, although known by that name, is really to be found in the Old Deer Park at Richmond, on a small eminence of made ground surrounded by flat park land and situated a few hundred yards south of the river Thames. The site was occupied during many centuries by an old Carthusian monastery, which was suppressed in 1541. The present building dates from about 1769, when George III erected it, after the designs of Sir William Chambers, to whom we owe also our Somerset House.

The building then became known by the name of the King's Observatory at Kew, though sometimes more correctly called the Royal Observatory at Richmond. George III provided the establishment with the best clocks and watches that could be obtained at the time, and he often visited the place, while his children frequently attended lectures given there. Our esteemed past president, Mr. R. H. Scott, was from 1871 to 1876 its honorary secretary, and from his interesting "History of the Kew Observatory"[1] I have gleaned the foregoing particulars.

About the year 1840 the Government came to the decision that the establishment should be abolished as an astronomical observatory, and the building was finally handed over to the British Association in 1842. The first resolution of the general committee of that body at the Manchester meeting in June of that year, with reference to their new acquisition, was "that Professor Wheatstone, Professor Daniell, and Mr. Snow Harris be a committee for constructing a self-recording meteorological apparatus to be employed in the building at Kew."

In the next year the name of Mr. (afterwards Sir Francis) Ronalds, F. R. S., first appeared in connection with the establishment. At the meeting of the British Association at Cambridge in 1845 a conference was held in connection with a committee which had been appointed to "conduct the cooperation of the British Association in the system of simultaneous magnetical and meteorological observations." This conference, among its recommendations, expressed the wish "that it is very highly important that self-recording meteorological instruments should be improved to such a degree as to enable a considerable portion

[1] Proceedings of the Royal Society, Vol. XXXIX, page 37.

of the observing staff of an observatory to be dispensed with."[1] This suggestion attracted the notice of two eminent scientific inventors—one, Mr. Clarles Brooke, F. R. S., who was my predecessor in this chair in the years 1865–66; the other, Mr. Ronalds, at the time on the staff of the observatory of the British Association at Kew, and who became subsequently its superintendent. Both gentlemen completed their inventions of self-recording magnetographs and meteorographs. The Brooke system was adopted by Sir G. Airy at Greenwich, the Ronalds system at Kew. At the date of the reorganization of the meteorological department of the board of trade, under a committee of the Royal Society, the Ronalds system of photographic barographs and thermographs was adopted for all their observatories and the Kew was constituted their central and normal observatory.

The verification branch of the observatory was first set on foot in connection with magnetic apparatus, and subsequently extended to meteorological and other instruments in the early fifties.

A walk through the building enables one to form but a very dim estimate of the work carried on there, but by the kindness of Dr. Chree, the superintendent, I have recently had the opportunity of visiting the place under favorable auspices.

As regards meteorology the institution is of incalculable value, for it is here that all English thermometers, with any pretensions to accuracy, are sent for examination and certificate. After being carefully compared with a standard in hot water, which is contained in a cistern with a transparent side, and also after being submitted to freezing and boiling temperatures, where necessary, the thermometers, if found correct, are marked by etching the "KO" monogram on the glass, and are sent out to the world with an established character for accurary. Barometers, hydrometers, and other instruments are also severely tested, examined, and marked at Kew, while watches and chronometers, after having been duly baked, frozen, tried in various positions, and carefully timed for months, are sent out with a certificate of the number of marks attained in the competition—100 would mean perfection—and the highest in 1884 reached 88.8. The Kew certificate adds considerably to the selling price of any instrument or watch. Photographic lenses are also examined and certified here, and recently a department has been established for the testing of platinum thermometers, a form of instrument which, though of little use to the meteorologist, is essential to the chemist or metallurgist who has to deal with very high temperatures.

It is at this observatory that the researches into the heights of the various forms of clouds were carried out by the late Mr. Whipple, whom we all so well remember. I show you a photograph of the apparatus he employed, and merely say in passing that the same cloud was at the same instant observed by two telescopes, one of which was

[1] Report of the British Association, 1845, page 71.

at the observatory and the other one some distance away in the park. A triangle could thus be constructed on a known base and with two known angles, so that the cloud height could be calculated with sufficient accuracy. Here is also found a glycerin barometer, in which glycerin is used instead of mercury, and it has, in consequence, a tube which is as many times the length of an ordinary barometer as the number of times mercury is heavier than glycerin. This results in an instrument over 30 feet in height, and with a much extended scale, so that it is easy to study by its means all the smaller changes in the density of the air, the surface of the colored liquid in the tube moving under our eye with unusual disturbances. Magnetic observations are also made here, much in the same way as those already described in the Royal Observatory, Greenwich, so that the two sets of observations usually check each other. Most of us remember the weekly weather curves published in the Times, but now, unfortunately, discontinued. These emanated from the Kew Observatory.

There are now meteorological observatories in all civilized countries, but the rough sketch I have given of these two of our own will enable one to form some idea of the subjects investigated and the instrumental means adopted.

HIGH-LEVEL OBSERVATORIES.

Let us now turn our attention to those observatories which are situated on the summits of mountains, and which by reason of their altitude attack the problems of air study from a much higher point of vantage. It must be clear to any person who has looked attentively at the sky that the motions of the upper air as shown by its clouds are very different to those of lower levels, and it is with a view of eliminating as far as possible the effects caused by inequalites of the ground, by friction, and by local circumstances that mountain peaks have in various countries been fixed on for the establishment of meteorological observatories.

MONT BLANC OBSERVATORY.

To begin with the highest in Europe, I must take you in imagination to Mont Blanc, which, as you know, is situated in France, and about 40 miles to the south of the Lake of Geneva.

In 1887 M. Joseph Vallot ascended Mont Blanc and made some preliminary studies on the summit, leaving some self-registering instruments there during the summer; and it was then that he formed the idea of erecting a permanent observatory on the mountain.

There were many difficulties owing to the great number and variety of the instruments which modern meteorological science demands, and M. Vallot instances that Saussure, in his famous early ascent (in 1787), contented himself with proving that carbonic acid existed in the air at these heights. Now it would be necessary to measure the exact quantity. M. Vallot pitched his tent at first on the summit, 15,781 feet above the sea, but afterwards, on a more careful survey in 1889,

finally decided to place his building on the rocks called Les Bosses, about 1,400 feet below the actual summit. He did this for two reasons, the first being that he was afraid of movement if he erected his observatory on the cap of snow, which is really glacial snow covering the summit; the second, that it seemed to him the highest spot where he could find a rocky foundation of sufficient size. In addition to these reasons a resting place and shelter were much needed by those overtaken by bad weather in making the ascent, and this latter consideration induced the guides and others in Chamounix not only to bear a large portion of the expense, but to carry up free of cost the various materials and instruments for the building.

In the summer of 1890 M. Vallot collected his materials and got them successfully transported to the "Bosses" rock, where he put up a tent for the workmen and another for himself. He suffered much from mountain sickness, but he had provided himself with a remedy in a steel tube full of compressed oxygen, of which he breathed several quarts, and then found himself with an appetite for food, and all was well. A storm came on, but by extreme exertion the workmen managed to put up the walls in one day, although at last it was so cold that they could scarcely work even in thick woolen gloves. Of course the porters had brought their burdens up as they best could, and M. Vallot says that by an unhappy fate all the useless things arrived first, and he sought in vain for the means of making a cup of coffee, though he was abundantly supplied with thermometers and other apparatus. For want of a coffee mill they spread the grains of coffee on a little table and ground them to powder by means of an empty bottle. He says that on this table were emptied coffee, soup, petroleum, and other things, so that to this day he does not know what mixture he then swallowed. They spent some fearfully cold nights, and some of the workmen fell ill, and M. Vallot had to revive them by giving them some of his compressed oxygen to breathe.

By the third day they got the roof on, and lit a triumphal bonfire at night to tell the folks at Chamounix that the enterprise was a success.

M. Vallot recounts how, in the dead of night, to his great surprise, he heard violent knockings at his door, and on answering them he found some of his porters, who had ascended with lanterns, to inform him that two of his scientific friends were ill with mountain sickness and sunstroke at the Grands Mulets rocks, 3,000 feet below.

He tells us that he immediately got up, filled an india rubber bag with three liters of oxygen, and descending to the Grands Mulets in one hour (though it had taken them six hours to ascend), he arrived at the cabin, gave his friend the oxygen gas, which enabled him to descend with a firm step to Chamounix.

Here M. Vallot found many of his packages detained, and after a successful forage among them says he emerged, brandishing as trophies a sphygmograph, a coffee mill, and a broom, the two latter things being

much wanted at the summit, to which they returned the same day in scorching sunshine. The whole narrative, as told by M. Vallot, is instructive as well as amusing.

On his next ascent he was accompanied by our esteemed Fellow, Mr. Rotch (of Blue Hill Observatory, Boston, United States), who at once commenced some important experiments on sunlight. M. Vallot has ascended many times, and he has published in his interesting Annals the scientific results of his observations. No one passes the winter on Mont Blanc, though M. Vallot has had an earnest letter from a lady, who says she is fond of solitude, and who wishes to pass the winter there in making observations.

The observatory contains various rooms for beds and a saloon for the guides, a spectroscopic and photographic observatory, a laboratory, a kitchen, and a room for the self-registering instruments. It is available for students of all nations, and already it has been utilized by observers, there having been, in 1893, four French scientific visitors, three Swiss, one German, one Italian, and one American. It is curious that our nation has not been among the first to make use of this building, nobly and gratuitously placed at their service by the heroic founder, who as soon as he knew I was about to read this paper sent me the photographs you have seen and the following letter, a translation of which will be interesting to you all:

JANUARY 2, 1896.

My first scientific expedition to the summit of Mont Blanc was in 1887, and some of the observations then taken are published in my Annals of the Observatory.

In 1890 I constructed the observatory on the "Bosses" rock at 4,365 meters altitude. Higher than this the summit is capped by a glacier, except where a few rocky points emerge from the surface, but which are too small to build upon.

No one lives in the observatory. During the summer only the self-registering instruments are attended to about every fifteen days. I have no experience of the winter there, but I have devoted three summers (1890 to 1893) to observations, which will be published in my Annals (Vol. II) sometime during this winter.

In 1893 M. Janssen, having announced that he was about to establish continuous observations, I ceased this class of work, so as not to do it twice over, and I am now devoting myself above all to the study of terrestrial physics, and I hope during this winter to publish my works on actinometry, on atmospheric whirls, on storm clouds, and on the transformation of snow into glacier ice.

Besides the observatory on the summit I have two meteorological stations, one on the Grands Mulets rocks at 3,000 meters and the other at Chamounix at 1,000 meters elevation. The last only is in constant use. The others are put in action when desired, and as I have said the four summers' observations that I already possess will suffice to give us some knowledge of the march of the ordinary phenomena of the air at such elevations.

In the summer I reside at Chamounix, and from time to time I go up to the observatory—about once a week at least—and I have thus made already twenty-one ascents of Mont Blanc. When at the observatory

I do my work as much on the actual snowy summit, which is quite near, as in the study which I have built. Life is not easy at these heights, for one has to contend with mountain sickness, but I have become so accustomed to the conditions that I can work there as well as when below, even when there are storms going on during the day or night.

Some few scientific men have also made use of the observatory, but at rare intervals.

After I had constructed my observatory, M. Janssen came here and worked, but he wished to make another of his own, and he placed it on the actual snowy summit of the mountain. He began in 1893, and continued during 1894 and 1895. It is nearly finished, but not yet completely furnished with instruments, so that up to the present no scientific work has been done. M. Janssen has abandoned the idea of permanently entertaining observers there. He has had constructed a superb meteorograph, which has this season been safely placed on the summit.

Unfortunately his observatory is placed on the snow, and has therefore no stability, for snow has continual movements of its own, and the clocks of the instruments are stopped. They have seldom gone for more than three days at a time. M. Janssen is very much disappointed, but he has told me that he intends to try other means. It will thus be some time before this observatory can give any results.

From an astronomical point of view, not much further progress has been made. The workmen who ascended to erect the telescope were too unwell to do the work. Two astronomical expeditions have not been any more fortunate, for the leaders of the same were seized with illness, and could do nothing, although they "saved the situation" by working at the lower level of 3,000 meters at the "Grand Mulet's" rocks.

To do any work at the summit, it is necessary to have been accustomed to exist at great elevations.

I am happy to be of any use to you, and I am desirous to see some English students working in my observatory. I offer my services to you and to your Society, as it is my principle not solely to work for myself, but to facilitate the labors of others by all possible means.

Yours, etc.,

JOSEPH VALLOT.

In his Annals, M. Vallot further says on the subject of establishing observatories on such elevated spots:

It is necessary to have been half-blinded by the snow, to have felt the thousand stingings of the atmospheric electricity, to have crawled prostrate over the soft snow, to have been blown over by the wind, and to have couched down before avalanches, ere one can give a correct account of the terrible intensity of the weather conditions at these great altitudes. It is after this that we comprehend the powerful impulses given to the upper regions of the air, and which are only feebly transmitted to the lower levels through an enormous mattress of atmosphere and vapor which serves to deaden its movements and falsify its indications.

Among the results already to be mentioned as coming from the Mont Blanc observations the following may be here enumerated, though a much longer list might be made.

The wave of diurnal variation of temperature is about one-third of the amplitude of that at Chamounix.

The experiences at the Mont Blanc Observatory confirm those of Mr. James Glaisher made in balloon ascents, the cold increases very regu-

larly at the rate of about 1° C. for each rise of 200 meters, which corresponds to 1° F. to 364 feet rise.

The temperature of the air on mountain slopes is sensibly less than in a free stratum of air at the same altitude as observed from a balloon. M. Vallot has given in his Annals, as far as possible, all the results as regards air pressure, moisture, temperature, wind, and weather generally, and he must be regarded as having made already, by the publication of his first volume, a real contribution to knowledge in a direction in which comparatively little has been done.

I must not leave the summit of Mont Blanc without showing you the observing cabin which has been gallantly pitched by M. Janssen on the very summit of the mountain, considerably higher, as you will have seen by the photograph, than the more permanent observatory of M. Vallot. The snow movements have for the present defeated M. Janssen, but it is not likely he will give up the attempt. M. Eiffel has also made an observing tunnel or gallery in the ice cap, and sundry timbers and objects placed therein will in the nature of things slowly sink with the glacier, and perhaps inform future ages of what has been done.

EUROPEAN MOUNTAIN OBSERVATORIES.

Time will not permit me to describe to you the other mountain observatories of Europe. There are many, from the Sonnblick in the Austrian Alps, where there is a well-found observatory at a height of over 10,000 feet, to the establishment of our own Ben Nevis, which only boasts the modest altitude of 4,406 feet.

I show you a few pictures representing this last-named observatory and its condition in mid-winter, when I think no one will envy the unfortunate observers who have to stay there, left severely alone.

AMERICAN MOUNTAIN OBSERVATORIES.[1]

This subject must not be quitted without mention of the observatory which has been perched on the Andes by the enterprise of the authorities of Harvard College in America.

I show you two views of this by the kindness of Professor Pickering. One shows the Arequipa station of the observatory at an altitude of 8,000 feet, while the other gives a view of the summit of El Misti in Peru, with the meteorological shelters erected there for the accommodation of the self-registering instruments, at the height of 19,200 feet above the sea, constituting this the highest meteorological station in the world.

Most interesting results can not fail to arise from this gallant attempt to pierce the clouds in search of knowledge. Mr. A. L. Rotch, of the Blue Hill Observatory, Boston, United States, has constituted himself

[1] See Mountain Observatories in America and Europe, by Edward S. Holden. 8vo, pp. 77. Smithsonian Miscellaneous Collections, Vol. XXXVII. Washington City, 1896.

the authority on high-level observatories, and I can refer the fellows with confidence to his many works, which will all be found in our library.

I must, however, show you one view of the Pikes Peak Mountain in Colorado, and I do this partly because in it Mr. Cohen has caught a very happy effect of cloud. The mountain is over 14,000 feet in height, and although on the south side it is approached by a gentle slope, yet on a nearer view from the east or west sides would be found to be intersected by deep gorges with precipitous walls 2,000 feet in height. On the observatory which surmounts Pikes Peak a wind velocity of 92 miles an hour was registered in December, 1892.

I also show you views of the observatory on the Brocken Mountain, and that of the Deutsche Seewarte at Hamburg, which latter enjoys the distinction of being the largest meteorological observatory in the world.

EIFFEL TOWER, PARIS.

From mountains to towers is a long step downwards, and I must ask you for a moment to listen to a few particulars about the observations taken on the Eiffel Tower in Paris, of which I show you a photograph, and I should have been glad to give you a nearer view of the meteorological appliances on the top, but, up to the present, it has been found impossible to get a satisfactory photograph of them on account of their elevated position.

On the top of the Eiffel Tower is a self-registering barometer, while in the Bureau Central Météorologique in the rue de l'Université, there is another, its exact counterpart, and it has been noticed that the first diurnal minimum of air pressure at 4 to 5 in the morning is much more evident at the top of the tower than at the base, while the first maximum at 9 or 10 in the morning is a good deal less marked on the summit than below. The second minimum of 14^h (2 to 5 in the afternoon) is also less on the summit; the second maximum at 22^h (10 in the evening) is sometimes a little more pronounced at the summit, but the difference is slight. The general corrected average pressure throughout the year at the top of the tower is lower by 0.12 millimeter, about four one thousandths of an inch, a difference not yet satisfactorily explained.

As to temperature, it is generally from 1° to 4° C. colder on the tower than below, the month of December being the only one where the temperature is higher at the summit than at the base. The changes of temperature are less regular, the diurnal variations not so large, while the smaller oscillations are much more marked at the summit than at the base, it often happening that some are registered above which are absolutely inappreciable below. Some of the changes of temperature recorded in the tower are very remarkable, as for instance a leap upward of 10° C. (18° F.), which rise of temperature took two days to communicate itself to the stratum of air below.

All this and much more of great interest to the weather student may

be found in M. Angot's masterly Annals, 1889 to 1892; and I have been favored by that gentleman with a letter giving some of his most recent results. It concludes as follows:

The only general result which is not to be yet found in my annual memoirs is the following:

The annual variation of temperature on the summit is already found to be very different from that at the level of the soil. The difference of temperature between the lower level and the upper amounts to 1.6° C. (2.9° F.) at its maximum at the end of June, while it is at a minimum at the end of September, when it only attains 0.3° C. (0.5° F.). The annual cooling of the air occurs much more rapidly below than in the upper air, a fact altogether analogous to that shown by the variations of the daily wave of temperature, and it frequently happens that in the months of September and October there is a mean temperature higher, in absolute value, at 300 meters altitude than on the ground. The inversion, therefore, which is constantly shown in the hourly means presents itself also in the monthly ones, but only in the autumn, and not in the coldest part of the year.

The society will be grateful to M. Angot for this preliminary note of some of his important conclusions.

M. Angot also calls attention to the following fact with respect to humidity:

Sometimes a process the reverse of evaporation has been noticed on the Eiffel Tower. After a cold period on one occasion, when a sudden warming of the air took place accompanied by great humidity, water rapidly condensed from the atmosphere, so that in three days as much as 9 millimeters (about three eighths of an inch) accumulated in the vessels used for evaporation experiments. Generally speaking, the atmosphere is nearly 8 per cent drier at the top of the tower than it is below.

Attempts have been made in our own country to secure observations on high towers, but as they have been of necessity confined to much lower altitudes, I must content myself with showing you the picture of the places where the two most notable experiments have been made, viz, Lincoln Cathedral and Boston church tower.

PRIVATE OBSERVING STATIONS.

One word about private observing stations. In addition to the telegraphic reporting stations of the Government, this society has a great number of observers in different parts of the British Isles, whose daily observations are published in our Meteorological Record. I show you a view of such a private installation, and in it you may recognize Mr. Mawley, a gentleman of whom you will know more by and by. Mr. Symons tells me that Mr. Mawley's station is so well arranged and conducted as to serve as a type and pattern for all others of the same order.

CONCLUSION.

I have now endeavored, as much as has been possible in one brief discourse, to give you some bare information as to observatories in our

own and in foreign countries, and it may be permitted to throw a glance from "the mind's eye" into the future and imagine an observatory in Great Britain which shall more than rival those of other countries. One can figure to oneself a tower piercing the sky from any of the elevated table-lands of this island, Salisbury Plain, the Stray at Harrogate, or anywhere on the downs between Guildford and Dorking, from which the most interesting results could not fail to accrue. It is the opinion of M. Vallot—no mean authority—that a high tower is for air-observing purposes equivalent to a mountain station of ten times the altitude, and this is evident when one considers that any mountain must act as an obstacle which thrusts the layers of the atmosphere upward into a contour almost like its own, so that some of the effects are very little different from those observed below. A tower like the Eiffel Tower, on the contrary, thrusts itself into the air without impeding its movements.

Among the new subjects which might with advantage be studied from such an observatory are the systematic photography of the clouds all around the horizon and the effects of observed refraction in the different air strata, a subject only yet in its infancy; for Mr. H. F. Newall showed only last Friday to the Fellows of the Royal Astronomical Society how he had observed, in the great telescope of Cambridge, waves of a varying speed and frequency crossing each other at different angles in the field of view when the telescope was pointed at the open sky. He says these belong to the upper air 4 or 5 miles from the earth, and if he is right (which I hope), here alone is a new field of study which may be fruitful of results in the future.[1]

It is the boast of our society that it is covering the face of the country, and indeed of the world, with a network of private observing stations, and it is collecting together for the enlightenment of all future time a mass of accurate knowledge on the subject of the thousand changes in our atmosphere, its varying moods, its beating pulses, its calms and its convulsions, so that when the philosopher is born who is destined to unravel all its mysteries he will find the means and instruments made ready to his hand.

[1] The Observatory, 1896, p. 77.

COLOR PHOTOGRAPHY BY MEANS OF BODY COLORS, AND MECHANICAL COLOR ADAPTATION IN NATURE.[1]

By Otto Wiener.

I.—Scope of the Investigation.

In the investigation of fixed lightwaves[2] I came at once upon the question of the fundamental possibility of color photography. Zenker had explained the processes then in use by the action of stationary lightwaves.[3] Objections to the explanation not as yet overthrown are offered in an article by Schultz-Sellack.[4] On this account, and because I was unacquainted with the possibility of the production of thicker transparent photographic films, I considered the solution of the question must be sought in other directions. These difficulties were, however, soon after overcome by Lippman,[5] and he succeeded in obtaining a process of color photography by a suitable production of stationary lightwaves, and thus by the application of Zenker's theory.

That this theory, however, explained the older processes was not yet proved, and I was unable to find anything looking to such a proof thoroughly established. I determined, therefore, to discover by new experiments the cause of the color production in the older procedures. These experiments form the point of departure and a considerable portion of the following communication.

The objections of Schultz-Sellack are by no means to be brushed aside without further consideration. He disputed the fact of regular fixed lightwaves in powders. Powdered substances had been used for color production in the first process of Seebeck, whose observations were

[1] Translated from Annalen der Physik und Chemie, Neue Folge. Band 55. 1895. Leipzig.

[2] Wiener, Annalen der Physik und Chemie, 40: p. 205, 1890.

[3] Zenker, Lehrbuch der Photochromie. Berlin, private publication by the author, 1868. In my earlier investigation I found that Lord Rayleigh also, in connection with the investigation of wave propagation in a medium of periodic structure (Philosophical magazine (5) 24: p. 158, 1887), had considered the possibility of this explanation. He was, however, unacquainted with the theory of Zenker published nineteen years before.

[4] Schultz-Sellack, "Upon the coloration of turbid media and the so-called color photography." Annalen der Physik und Chemie, 143: p. 449, 1871.

[5] Lippman. Comptes rendus, 112: p. 274, 1891.

published in Goethe's "Farbenlehre,"[1] in the year 1810. Seebeck used moist chloride of silver which had become gray by the action of light, spreading this upon paper.

Schultz-Sellack's objection applies with the greatest force to processes where paper is coated with the substance sensitive to light by soaking it in different solutions, as, for example, in Poitevin's process. It does not, on the other hand, apply in those which make use of a uniform transparent layer of a substance sensitive to light with a good reflecting background, as the processes of Becquerel, in which bright silver plates are chlorinized to a determined depth by electrolysis.

A second objection of Schultz-Sellack is raised against the possibility of the satisfactory production of colors by a mechanical division of the layer brought about by the exposure, the degree of which would be determined not by the colors but by the intensity of the light. The coloring would, under these circumstances, be only accidental. This explanation is in reality shown to be erroneous in chapter five.

New doubt concerning the general validity of Zenker's theory is raised by the investigations of Cary Lea[2] on the haloid salts of silver. He showed that the colored substances produced by the action of colored light on chloride of silver already exposed may be produced by purely chemical methods in the dark.

H. Krone[3] also has recently given a series of reactions for the Poitevin process which are carried through by the exposure, and by which different colored bodies may be produced in the sensitive substances by purely chemical means. He announces, therefore,[4] "The method of Poitevin rests upon purely chemical processes," and is "totally different from that of Lippman." But he also makes the following remark:[5] "This causal connection"—namely, between the color of the light and the above-mentioned bodies which may be produced by chemical means—"is of a purely physical nature, and is only to be explained with reference to the processes and by the progress of investigation upon wave motion and the nature of light."

If, now, the Zenker theory has no application in this case, it is not expressly stated wherein the verification fails. On the contrary, Krone asserts[6] "that our present knowledge of the method of photographic production of colors, so far as this has until now been chiefly deduced,

[1] Goethe Farbenlehre 2: p. 716. The there communicated memoir of Seebeck I found in none of the editions of the complete works of Goethe which I could command.

[2] Carey Lea: "On red and purple chloride, bromide, and iodide of siver; on heliochromy and on the latent photographic image." American Journal of Science, series 3, 33; p. 349, 1887.

[3] In an address published in the Deutsche Photographen-Zeitung, p. 327, ff. 1891, and in his book "Darstellung der natürlichen Farben durch Photographie," published by the Deutsche Photographen-Zeitung, p. 43, 1894.

[4] In the beginning of the same address.

[5] Loc. cit., p. 49.

[6] In his book, p. 38.

rests upon Zenker's theory." He implies that the knowledge is not as yet firmly established, and this may be inferred also from the following sentence, which finishes the treatise above cited: "We may assume, in consideration of the color processes of which we have been speaking"—those which I have designated as old—"that the resulting colors appear the same to us as the colored lights used in the exposure, because the molecules of the layer exposed continue to vibrate with the same wave lengths which they encountered in the light to which they were subjected."

The assumption thus made in the last sentence leads however to no explanation of the color results; for since the place exposed does not become self-luminous, the further vibrations of the molecules must result in the absorption of the colors before illuminating and the place would appear of the colors complementary to these.

In this state of affairs the fundamental question must first of all be proposed: Are the colors appearing in the older processes apparent or body colors—that is to say, produced by interference or absorption?

In the first case, which is the one required by Zenker's theory, it must be further asked: How is it then possible that the same colors may be produced by chemical means? Is it possible that by chemical action a body may be produced with a stratified structure which is capable of producing interference? Krone[1] indeed alleges this extraordinary possibility; and it becomes clear that in this case one may distinguish a process as chemical without contradicting Zenker's theory.

In the second case however Zenker's theory is not applicable, and one is confronted by the remarkable, and for my science new, issue, the fundamental possibility that colored illumination can create corresponding body colors. Yet in these circumstances one might perhaps fall back on the consideration that absorption and interference may not be fundamentally different. Thus absorption follows from the interference theory developed by Wrede.[2] Such an assumption is not however compatible with the fact that the metals show the characteristics of absorption at a thickness of about $\frac{1}{100}$ the wave length of light. It is fundamentally contradicted moreover, as was shown long ago by Stokes and Rudberg, by the fact that absorption is connected with a loss of light whose energy is changed into other forms, as for example, into heat or chemical energy, while with interference alone no light is lost, the reflected and transmitted together being always equal to that incident, and in the case of white light complementary to each other.

But why is it that the question as to the source of the colors in the older methods of color photography has not already been easily decided? Zenker[3] gives the answer to this question. The fundamental substance in these is chloride of silver or a lower chlorine compound of this salt.

[1] In the address above cited.

[2] Wrede's theory and refutation, see Wüllner, Lehrbuch der Experimental-Physik 2: p. 456, 4th edition, 1883.

[3] Zenker. Photochromie, p. 85.

The index of refraction for pure chloride of silver is about 2, and for compounds poorer in chlorine probably even greater. When therefore a ray of light falls upon silver chloride even with a considerable angle of incidence, it would pass within nearly perpendicular to the surface, on account of the great index of refraction, and the difference in path for interference as compared with direct incidence is only slightly changed. The index of refraction of the sensitive layer in Lippmann's process on the other hand, which consists chiefly of collodion or gelatine, is only about 1.5. Here the angle of incidence becomes of importance, and the colors change with it in a way not to be desired.

The interference nature of the colors and the stratification of the Lippman gelatine plates may be recognized in another way. Different observers[1] breathed on such plates and saw appear in place of the original colors others of greater wave-lengths. This showed that the colors depend on a changeable distance, namely, that between the elementary mirrors within, which was increased by the swelling of the gelatin.[2]

I have repeated this experiment, and before large audiences have replaced the breathing on the plates by the use of a stream of vapor. In the photograph of the spectrum thrown upon the wall the colors were transformed with great rapidity in the direction of the violet end of the spectrum and returned again as the moisture was driven from the gelatin film by a Bunsen burner. This experiment can not, however, be performed with the older processes.

Zenker[3] sought to give the light rays in chloride of silver a greater angle with the normal to the surface by sending them first through a liquid of high index of refraction, but without result. This expedient must fail so long as a plane parallel layer of such a substance is used. For by the refraction in this the original angle of incidence is decreased. Such a diminution can not occur when the beam of light enters the bounding surface of the auxiliary substance at right angles. Thus a new experiment was suggested.

I used a right-angled glass prism with an index of refraction of 1.75 for the D lines. This was laid with its hypotenuse surface upon the color picture and the intervening air space filled up with a layer of benzine. For light rays entering normal to the side surfaces an angle of incidence of 45° is thus secured in the strongly refracting medium, and the ray entering the chloride of silver must, therefore, form a consider-

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[1] Meslin, Ann. de chim. et de phys. (6), 27, p. 381, 1892; Krone, "Darstelling der natürlichen Farben," p. 66; Valenta, "Die Photographie in natürlichen Farben," p. 68; Halle a. S., published by Wilh. Knapp, 1894.

[2] Dr. Neuhauss (Photogr. Rundschau, p. 295, 1895) mistakenly believed that he had found an objection to the applicability of Zenker's theory to Lippmann's process in the observed magnitude of the grains in the undeveloped plates, which was found to be 0.0003 millimeter. Not the absence of grains, as he supposes, but complete transparency is requisite for the production of fixed light waves.

[3] Zenker. Photochromie, p. 85.

able angle with the normal to the surface. The difference of path of the interfering light waves will, in comparison with vertical incidence, be greatly changed, and according as the colors are thus altered or not are they interference or body colors. A description and theory of this prism experiment follow in Chapter XI, below.

If, now, the spectrum were produced according to the method of Becquerel, the surprising result appeared that a portion of the spectrum observed through the prism appeared when compared with that observed directly through the air to be considerably displaced toward the extreme red. This is exactly the color shifting which is to be expected if the theory of Zenker is correct.

Zenker, therefore, deserves the credit of having, in the year 1868, rightly recognized as the cause of the coloring in the Becquerel process the action of fixed light waves.

The photographic substance is in Seebeck's method the same. The only difference lies in the form. Seebeck used powder, Becquerel a homogeneous film of silver chloride mixed with subchlorides. The color displacement in the prism experiment is to be expected to occur with the same prominence as with the Becquerel plates. The displacement is in fact, however, not to be observed, and just as little in the Poitevin process.

The objection of Schultz-Sellack is shown to be valid exactly in those cases where it would appear plausible from previous considerations; for in fine powder and in paper one could expect no regularly arranged stationary light waves.

But the question may properly be asked, Why are there not created in the Becquerel plates body colors as well, since these plates contain the same substance as those of Seebeck? It does not appear impossible that, besides the interference colors demonstrated to be present, there may also be body colors. I was, indeed, able to show that in the method of Becquerel body colors also cooperate. The proof of this may be found in Chapter XI, below. The colors on plates of Seebeck and Poitevin are, on the contrary, exclusively body colors.

There are, therefore, methods of color photography which can not be explained through application of the theory of Zenker; and there are substances in which colored illumination gives rise to corresponding body colors, in which the coloring is not due to interference, but to a characteristic absorption determined by the chemical constitution.

But how is such a phenomenon conceivable? The idea of a possible answer came to me in reading the above-mentioned memoir of Carey Lea. The various colored compounds of chlorine and silver which he mentions are, according to him, molecular compounds of silver chloride and protochloride, but not to be expressed by definite number relations. He groups them under the name of "photochlorides." These colored compounds are also formed by the action of light upon a ground consisting of silver chloride and protochloride, such as is at hand in

Seebeck's process, for example. That such compounds are formed most readily under the action of light is not difficult to suppose.

But why are the compounds formed of the same color as the illumination? Why, for example, should a red photochloride be formed under the action of red light in preference to some other?

It has the physical advantage that it reflects this color better than compounds of other colors. Colored light that is reflected is not absorbed, and can therefore cause no decomposition, for which the absorption of light is requisite. Of all possible compounds which can result from the disturbance of the chemical equilibrium by the action of the light, the red compound possesses the advantage of stability on continuing the exposure. According to the conceptions of the kinetic and newer chemical theories, we must, however, assume that in the disturbance of the equilibrium all possible compounds are, temporarily, actually produced by some of the groups of molecules. Among these, only the red continue unchanged, while those of other colors absorb the red light and are by it further decomposed.

This is an explanation of the phenomenon easily deduced from admitted facts and observations. Its correctness may be readily tested, for it requires that, for example, the red compound shall be decomposed by other than red illumination while stable in red light.

Such an experiment appears in the researches of Carey Lea.[1] He threw a spectrum upon the rose-colored photochloride. All the colors except red changed it in such a way as to impress their own hue upon it more or less, but "in the red it remained unchanged."

I myself made experiments to test this explanation, in which the sensitive plates were exposed to the action of two spectra crossing each other at right angles. These experiments, which are described in Chapter XIII, confirmed the correctness of the explanation.

A substance which, corresponding with this explanation, has the characteristic of giving corresponding colors, I call a color receptive substance. This characteristic is discussed in Chapter XII.

By this connection a new foundation is laid for further methods of color photography, for the phenomenon is not restricted to particular substances. It appears that any coloring matter which can, under certain conditions, be decomposed by light is suited to use with new methods.

It must be remarked that the difficulty to fix these colors appears from the nature of the method of their formation inevitable, for the capacity of the sensitive substances for reproducing colors is due to their decomposition by the action of light. Indeed, the colors in the older processes could only be fixed in a very limited degree. It is intimated in Chapter XIV in what manner success may perhaps be reached in this direction.

In connection with the characteristic of color reproduction the acquisition of a capacity for resisting outside actions may be called an

[1] Carey Lea. American Journal of Science (3) 33, p. 363. 1887.

adaptation. Thus colors so produced may be called adaptation colors, at the same time remembering that a physical chemical, and in the last analysis a mechanical process, is in consideration. An adaptation of such a character may be distinguished as a mechanical adaptation.

The question arises whether there may not be in nature, rich as it is in color, sensitive substances with the same characteristics as the ground of these photograms. Can not certain adaptation colors in nature be thus explained? To be sure one is accustomed to regard the adaptation in nature in the light of the fundamental law of Darwin of the natural perpetuation by the selection of advantageously altered forms of life. I am not, however, concerned with such a biological adaptation, but only with a mechanical. This conjecture appeared to be confirmed by observations which I found in biological works lent me by the kindness of Professor Oltmanns, of Freiburg.

I came first of all on the following remark in the work of Theodore Eimer: "Die Entstehung der Arten auf Grund von Vererben erworbener Eigenschaftung nach den Gesetzen organischen Wachsens. Ein Beitrag zur einheitlichen Auffassung der Lebewelt."[1] Eimer opposed a too far-reaching estimation of the effect of biological adaptation in the agreement of the color of an animal with its surroundings, and pointed out a possible chemical action of light in cases of quick color changes. It has been observed "that butterfly pupæ are during their development influenced by the color of their surroundings so far that they assume these colors." . . . "for example the red color of a cloth enveloping them." In explanation of this remarkable observation he assumes that the substance of which the chrysalis is composed "is of such a character that it serves the purpose so ardently sought at present of color photography."[2] In the possibility of such a connection I am justified in making mention of this circumstance without having verified the explanation by experiments of my own. It would be scarcely possible for me to add anything new to the excellent, thorough, and protracted experiments which Poulton[3] has carried out on the color adaptation of the caterpillars and their pupæ.

According to these observations, one would not be justified in comparing the skin of caterpillars directly with a photographic plate. These are in addition physiological processes. Nevertheless, I will attempt to show from the observations of Poulton that the pigment of the caterpillar's skin during the sensitive states possesses in some degree the peculiarities of a color-receptive substance.

But if mechanical adaptation occurs in this case, can it not have a more general application in the formation of the living world? I found this supposition confirmed in a paper of August Weismann "Aeussere Einflüsse als Entwicklungsreize."[4]

[1] Eimer, Jena, published by Gustav Fischer, 1888.

[2] Loc. cit., page 155.

[3] Poulton. For the citations, see Chapter XV.

[4] A. Weismann. Jena. Published by Gustav Fischer, 1894.

He calls the process here designated as mechanical adaptation, so far as it plays a part with living beings, "intra selection,"[1] and refers to a work of Wilhelm Roux, which appeared in 1881, "Der Kampf der Theile im Organismus, ein Beitrag zur Vervollständigung der mechanischen Zweckmässigkeitslehre."[2] The latter designates the process as "functional adaptation," and discusses it in a general way as caused by the "strife of the molecules," "strife of the cells."[3] As "molecules" he understands the smallest organic process units. In the case at hand, "molecules" is to be taken literally.

Indeed, the result of colored illumination in a body may be figuratively expressed as the victory of the similarly colored molecules over those dissimilarly colored, won by reason of their capacity of best reflecting the incident light. Thus the application of the explanation of the older processes of color photography to the explanation of certain adaptation-colors in nature leads to the arrangement of these phenomena under general groups, which may be recognized as processes of mechanical adaptation.

I proceed now to the experimental verification and the exact foundation and working out of the matters above mentioned. First of all, I must express my thanks to Professors Arzruni, Grotrian, Holzapfel, and Wüllner, of the technical college of Aachen, for their assistance. Since, unfortunately, I found it hard to judge of many of the finer differences of color, I have given no observations of color unless they had been made or checked by one or more of these gentlemen.

II.—Apparatus and Procedures.

For the photography of the spectrum a Steinheil spectrum apparatus was used, in which the ocular was replaced by a small photographic camera. This could be screwed to a tube which fitted in the telescope tube. The adjustment was performed by means of a rack and pinion motion.

The width of the slit was about 1 millimeter when great brightness was wished and about 0.5 millimeter when a spectrum of greater purity was desirable. The length of the spectrum from A to H_2 was 19.2 millimeters. Its height was generally between 15 and 18 millimeters.

The source of light was usually the electric arc of a large Schuckert lamp, used with an average current strength of 30 amperes, and whose positive carbon had a thickness of about 23 millimeters. The carbons had an inclination of 45° to the vertical, so that the greatest light intensity was sent out in a nearly horizontal direction. The time of exposure varied from a half hour to an hour in general, though under the most favorable conditions colors were produced after a few minutes.

[1] Loc. cit., page 6.

[2] W. Roux, Leipzig. Published by Wilhelm Engelmann.

[3] The strife of the tissues and the strife of the organs is, as Roux remarks, not to be included in the same category, because dissimilar parts then enter into combat.

I designate as the Seebeck process in general that in which the sensitive material is preliminarily exposed chloride of silver powder.[1] I used in this pure chloride of silver precipitated in the dark and then dried. The powder was then placed between two glass plates and the edges of these cemented together. The preliminary exposure was made at first with violet and ultraviolet, but later more quickly with white light. It was continued until the powder had taken on a not too dark violet color.

Becquerel[2] has experimented with various modifications. I used exclusively and distinguish here as the Becquerel process that peculiar to him, and employed electrolytically chlorinized silver plates, but without subsequent heating. For their preparation I used brightly polished electrolytically silvered copper or brass plates or else thin sheets of silver themselves. There were dipped in a weak solution of hydrochloric acid (1:8) as positive electrode, while a current of from two to four amperes passed between surfaces of about 30 square centimeters area for some seconds. The thickness of silver chloride deposit recommended by Becquerel as the most satisfactory was attained by the passage of a quantity of electricity which would suffice to separate 0.067 cubic centimeters of hydrogen per square centimeter of silver surface. This thickness is according to an approximate calculation about 0.0016 millimeters. After coating, the plate is quickly dried between filter papers, and then rubbed with soft leather.

Poitevin's[3] process was used by Zenker and Krone and developed by them.[4] Following their directions I bathed Rives-Rohpapier in a 10 per cent solution of common salt for two minutes, then for one minute in an 8 per cent solution of nitrate of silver. The leaf was then quickly washed and was exposed in diffused daylight to the action of a stannous chloride solution containing 5 grams of stannous chloride to 100 cubic centimeters of water, till it had attained a not too dark coloration. After this it was bathed in a mixture of one part concentrated potassium chromate solution and two parts concentrated copper sulphate solution and preserved between filter papers. It is well to moisten the paper somewhat before exposure if quite dry.

Development is of course unnecessary in any of these processes, as the colors are formed during the exposure.

Fixing, which in the last of these methods is possible to a slight extent, I have not undertaken.

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[1] See citation, p. 168. All these processes are described in the books of Zenker (see p. 225) and Krone (see p. 227).

[2] Edmond Becquerel, Annales de chimie et de physique (3), 22: page 451, 1848; 25: page 447, 1849; 42: page 81, 1854; see also E. Becquerel, "La Lumière," 2: page 209. Paris, Firmin Didot Frères, Fils et Cie, 1868.

[3] Poitevin. Comptes rendus, 61: page 1111. 1865.

[4] See the work already mentioned.

III.—Chemical Relations of Chloride of Silver during Exposure and Electrolysis.

It has been lately shown conclusively by Guntz[1] that in the exposure of silver chloride to light silver protochloride is formed. Pure silver chloride not exposed to light appears, according to Becquerel,[2] to be appreciably sensitive, when exposed to the spectrum, only to violet and ultra violet light, and takes on during exposure a violet color. I have repeated this experiment with the same result. The resulting powder, composed of silver chloride and protochloride, is, however, sensitive to all colors of the spectrum and copies them to a certain degree.

It would be desirable to investigate whether pure silver protochloride is changed in the spectrum. Dr. Hermens, assistant in the technical chemical laboratory of this institution, has with great friendliness endeavored to prepare some of this salt for me, following the directions of Guntz.[3] It appears, however, to be very difficult to obtain it free from silver chloride. Guntz, indeed, secured no pure silver protochloride.

The chemically prepared silver protochloride behaves in the spectrum in the same way as exposed silver chloride. This experiment, therefore, forms a confirmation of the proof of Guntz of the formation of silver protochloride by the action of light on silver chloride. The mixture of silver chloride and protochloride had the violet appearance of exposed silver chloride.

The electrolytically prepared chloride of silver contains also some silver protochloride. For it is sensitive to all rays of the spectrum. It can not, however, be exclusively silver protochloride; for in one experiment I obtained a plate which was sensitive only to violet and ultraviolet rays, and which therefore contained only silver chloride. In its preparation I had not observed the conditions of the experiment. It was probably produced by too weak a current, for I later prepared a plate with a current of 0.2 amperes which was very sensitive in the ultraviolet but only slightly so in the visible spectrum. It must therefore be assumed that Becquerel plates thus prepared consist principally of silver chloride with some protochloride, the quantity of which is increased with stronger currents. In confirmation of this it may be remarked that when the layer is lifted from the silver surface it appears of a bright violet color, by transmitted light.

IV.—The Accuracy of the Color Reproduction in the Older Processes.[4]

Becquerel's plates give the colors by far the best. They appear bright, similarly to those produced by Lippmann's method, and in the right places.

[1] Guntz. Comptes rendus, 113: page 72. 1891.

[2] Becquérel, Annales de chimie et de physique (3), 22: page 452. 1848. See also Zenker, Photochromie, page 18.

[3] Guntz. Comptes rendus, 112: page 861. 1891.

[4] See also Zenker, loc. cit.

In neither of the other processes are the colors so accurately reproduced, and they look dull. The Seebeck plates show besides violet only blue and red distinctly, and the latter is a sort of rose red, the former being often rather grayish. Green is very indistinct and yellow, hardly to be distinguished. But there appears in their places a considerable brightening of the violet background. The Poitevin process is superior to that of Seebeck. All the colors appear, but there is a predominating yellowish brown tone. The yellow parts of the spectrum are, as reproduced, more of an orange color, similar to the color of a paper soaked with potassium bichromate solution.

V.—Incorrectness of the Explanation of the Reproduction of Colors according to Schultz-Sellack.

A transparent film of silver iodide produced by the action of iodine on a silver mirror chemically precipitated on glass is, according to Schultz Sellack,[1] not chemically changed by the action of light, since there is nothing at hand to absorb the iodine. The surface is, on the other hand, mechanically disintegrated to a very fine powder.

I observed such a film under the microscope, and determined the diameter of the grains to be about 1 μ (thousandth of a millimeter) with a space between them of from 0 to 3 μ. The yellow, unchanged iodide of silver film was visible through them.

The series of transmitted colors succeeding under the influence of sunlight is, according to Schultz-Sellack, yellowish brown, dark brown with stronger illumination, red, green, blue, bright bluish white; finally, the film is, with slight exposure, almost completely colorless and transparent. I observed also such colors, but since a strong and steady beam of sunlight was inaccessible to me, I used an electric light, with which it was impossible to secure uniform action. Parts of the iodide of silver film exposed equally long to light attained different colors.

But only violet and ultraviolet rays are able to cause this mechanical disintegration as I found in confirmation of the results of Schultz-Sellack. Herein lies the possibility of forming different colors by different intensities and durations of exposure. A representation in different colors can therefore apparently be obtained "which is able to distinguish the different intensities of violet light, which are transmitted by red, green, and blue glass."

These colors are held by Schultz-Sellack to be diffraction colors, because they appear most strongly when one observes the plates in a darkened chamber opposite to a small light opening. Indeed, the colors are very dull when viewed by diffuse light. But they fail to show the characteristic property of diffraction. They do not appear in a direction at an angle with the incident ray as with a grating, but in the direction of the rays passing through and reflected.

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[1] Schultz-Sellack. "On the chemical and mechanical change of the silver haloid salts under the action of light." Annalen der Physik und Chemie, 143; page 439, 1871.

The colors of iodide of silver are, however, not those due to thin films, for they change "when one replaces the air in the interlying spaces by water or varnish." It would be consistent with this observation to suppose that they are caused by the interference of light passing through the iodide of silver particles and that passing directly through the intervening spaces.

I refrain, however, for the sake of brevity, from more thoroughly examining this hypothesis. The question at present considered is this: Are the methods of color reproduction in the older processes of color photography satisfactorily explained, according to Schultz-Sellack, by supposing the colors to be in consequence of mechanical disintegration of the film, so that they may be called disintegration colors? A grave objection occurs to such an explanation, because they are thus classed as transmission colors while in each of the processes the colors are reproduced in reflected light. Since, however, the disintegration colors do not appear in directions at an angle with that of transmission, it follows, if they are caused by interference, that reflected and transmitted light must be complementary to each other, leaving out of consideration the small absorption in the iodide of silver. I actually found that where a metallic yellowish green was seen in normally reflected light that passing through was bluish violet and where blue was reflected yellow was transmitted. Hence, the series of Schultz-Sellack can not hold for the colors of reflected light, for according to it the more refrangible occur by increasing the time of exposure or the intensity of the light.

The simple appearance of the colors of the older color photography works against the theory of Schultz-Sellack. They appear very well by diffuse illumination, as from a bright window, while disintegration colors are here extinguished. These latter require for viewing a light directly reflected from in front, which would totally destroy colors from bright plates like those of Becquerel, for the light reflected from the front surface would overpower that from behind.

Disintegration colors, according to his observation, experience also a change in reflected light with increasing angle of incidence. I was able in this way to produce change from metallic yellow to bluish gray and back to metallic yellow. It has not been possible to produce such changes with reproductions of colors by the older processes.

The Schultz-Sellack explanation may, however, be subjected to a crucial test, for the different colors of illumination would produce no different kinds but only different intensity of action upon the sensitive film, and if the nature of the colors resulting is to be determined only by the intensity all colors of illumination would in the beginning produce the same color, and so far as their action proceeded the same succession of colors.

Such a behavior is contradicted by the observation of Becquerel, according to which the colors corresponding to those of illumination

are from the beginning pure, though weak. The beginning of the action, therefore, causes not the same but different colors.

For a more convenient test I caused to be formed on a sensitive film a series of spectra with corresponding colors opposite, but giving different exposures to the several impressions. For this purpose a shutter was placed across the slit and opened upward. Thus, after the close of the experiment, one could at a glance observe the action of the differently colored illumination. It was shown conclusively in this way that the several colors did not at the beginning of the exposure give rise to one but to different colors, which were similar to the colors of the illumination.

The following are the observations of Professor Grotrian, with a plate prepared by Becquerel's process:

FIELD 1. One minute time of exposure. Trace of red. Yellow and green only noticed when field 2 is also under observation. Blue absent.

2. Two minutes. Red stronger; yellow and green to be recognized. Blue absent.

3. Four minutes. Red, yellow, and green stronger. Blue scarcely to be recognized.

4. Eight minutes. Red, yellow, and green stronger. Blue to be recognized.

5. Sixteen minutes. Red, yellow, and green stronger. Blue still weak.

6. Thirty-two minutes. All colors stronger.

The action in the ultraviolet was first apparent in the second field; hence, after the red.

Red is here. the first distinctly visible color, and appears under the influence of red light. This must, therefore, according to Schultz-Sallack, be the most powerful acting color of all, and at the same time red must be the first stage of the disintegration colors. Other colors, or lighter stages in the disintegration coloring, can only be caused at first by red light, and red coloring must be the first result of other colors of illumination.

Observation shows the reverse. The other colors are caused by other colored illumination. while the red is not changed by continued red illumination, but on the contrary grows stronger.

The same experiment was performed with Seebeck's and Poitevin's plates with the same result. Before the first color to appear had changed the other colors appeared in their places.

Schultz-Sellack's explanation of the formation of colors in the older processes of color-photography by disintegration colors is, therefore, incorrect.

I do not in this, however, assert that the intensity of illumination is without influence on the color produced. Such an influence is as apparent as in the Lippmann process.[1] To disprove his assertion, it is not, however, necessary to prove a complete independence of the colors from the intensity of the light, but only to show the error in the relation between them which his hypothesis requires.

[1] See for example Krone, Annalen der Physik und Chemie, 46, p. 428, 1892.

VI.—The Prism Experiment.

The prism was so placed upon one-half of the photographed spectrum that the line between the hypotenuse and the side face I (fig. 1) cut similar color-lines at right angles. The eye of the observer was placed in the prolongation of the same surface I (the arrow indicates the line of vision) so that a line S drawn, before the experiment, in the direction of a single color, as, for example, the yellow appeared straight when viewed through the air and prism.

It can then be calculated what change the color at the line S under the prism must experience as compared with that in the air if the colored image is caused by stationary light waves.

That color appears in general whose wave length is equal to the difference in path between two rays reflected at two adjacent elementary mirrors.

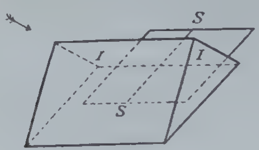

Fig. 1.

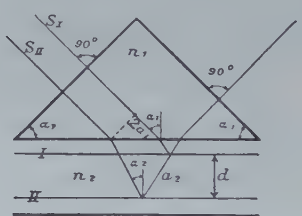

Fig. 2.

Let I and II in fig. 2 be two such elementary mirrors at a distance d apart in a medium of an index of refraction n_2. The rays are incident in the general case at the angle α in an equilateral prism of index of refraction n_1 and a base angle α_1, so that the rays pass through the sides of the prism at right angles both in entering and leaving.

The plane parallel liquid layer between prism and photographic film has no influence on the difference of path between the interfering rays S_I and S_{II}, and neither do the phase-changes on reflection at I and II.

Let $2\,a_2$ be the excess of distance of S_{II} over S_I in the layer, and α_2 the angle which S_{II} makes within the layer to the normal to the mirror.

Let $2\,a_1$ be the excess of S_I over S_{II} in the prism.

If we denote the wave length in air by λ the difference in path between S_I and S_{II} is then measured in wave lengths as follows:

$$D = 2a_2\frac{n_2}{\lambda} - 2a_1\frac{n_1}{\lambda}.$$

But

$$a_2 = \frac{d}{\cos\alpha_2} \text{ and } a_1 = d\tan\alpha_2\sin\alpha_1$$

Therefore

$$D = \frac{2d}{\lambda}\,\frac{n_2 - n_1\sin\alpha_1\sin\alpha_2}{\cos\alpha_2}$$

But since

$$n_1 \sin \alpha_1 = n_2 \sin \alpha_2,$$

$$D = \frac{2dn_2}{\lambda} \cos \alpha_2 = \frac{2dn_2}{\lambda} \sqrt{1 - \frac{n_1^2}{n_2^2} \sin^2 \alpha_1}.$$

Generally in observing the photographic film one looks perpendicularly upon it. In this case $\cos \alpha_2 = 1$ and

$$D = \frac{2dn_2}{\lambda}$$

The difference in path of the two rays is a wave length when $D = 1$ since D is measured in wave lengths. The color then appears whose wave length is

$$\lambda_0 = 2dn_2;$$

hence that which is caused by the stationary wave.

In the general case however $D = 1$ for another wave length:

$$\lambda = 2dn_2 \cos \alpha_2 = \lambda_0 \cos \alpha_2.$$

One is thus able to obtain these values by multiplying λ_0 by a factor

$$f = \cos \alpha_2 = \frac{\lambda}{\lambda_0}.$$

The degree of the color change is thus determined, that is the relative wave lengths of the altered and the original color.

Let these be designated in the case of incidence less than 45° in air with f_1 in the prism with f_p.

(1) Then

$$f_1 = \sqrt{1 - \frac{1}{2n_2^2}}$$

(2)

$$f_p = \sqrt{1 - \frac{n_1^2}{2n_2^2}}$$

Let ratio f_p/f_1 be designated as f_{pl}. It determines the color change in the experiment described in this chapter in which a part of the colored image is viewed through air, another part through the prism. It is:

(3) $$f_{pl} = \sqrt{\frac{2n_2^2 - n_1^2}{2n_2^2 - 1}}$$

The equations (1) to (3) show also in what ratio the wave lengths of the colors observed must change if the indices of refraction of the photographic film and of the prism are known. They can conversely serve in the case f and n_1 suffer a known change to calculate the index of refraction n_2 of the layer. Thus, the question may be answered, given a value n_2, how great an index of refraction the prism should have in order that f shall have a value markedly different from 1, so that there shall be a distinct color change. To be sure, one could make use of greater angles of incidence than 45°: but then the reflection from the upper surface of the film might easily be so strong as to destroy the value of the experiment.

VII.—Prism Experiment with Color Reproductions After Becquerel—First Proof of their Interference Nature.

Although the results of the previous chapter do not require experimental verification, yet I may say that in a prism experiment with a photograph of the spectrum by Lippmann's interference method I observed a very considerable color change. In a place where for normally reflected light about the color of the yellow sodium lines appeared, the color when viewed through the prism appeared on the border between blue and greenish blue, or about at the place of the hydrogen line H_β (F). The angle of incidence was less than 45° and the prism used had a refractive index $n_D = 1.52$.

In the following observations I used exclusively the already mentioned prism for which $n_D = 1.75$, and at an angle of incidence of 45°.

When one observed a line drawn in the middle of the yellow on a Becquerel plate, the ground in its vicinity when viewed through the prism appeared green. Another line drawn along the border between green and blue appeared through the prism lying in the middle of the blue. In another plate the mark was drawn on the boundary between yellow and green and it formed the boundary between green and blue as seen through the prism.

The experiment was repeated with homogeneous illumination from a sodium flame. There was then perceptible in the yellow of the photographic spectrum a bright strip of about 1.5 millimeters breadth, the center of which appeared to be shifted about 2.1 millimeters toward the red when the reference mark was undeviated. This value is the mean of the measurements of several observers. The magnitude of the displacement happened to be exactly the distance from the D to the C line in the spectrum. From this follows:

$$f_{pl} = \frac{\lambda_D}{\lambda_C} = \frac{589}{656} = 0.90.$$

From this change in the wave length of the reflected light the index of refraction of the photographic film may be obtained by substitution in equation (3) with the value of $n_1 = 1.75$. Such a computation gives $n_2 = 2.4$. In a second plate a displacement of 1.2 millimeters was observed, from which it followed that $f_{pl} = 0.94$ and $n_2 = 3.1$.

That the index of refraction of the film should vary when they are not prepared under exactly the same conditions is obvious, for the value of the reflective index depends on the proportion of silver protochloride to the silver chloride in the film. According to Chapter III the latter is, however, probably the chief constituent of the film, so that it would be unlikely that the index of refraction should greatly exceed that of chloride of silver. This is by the observations of Wernicke,[1] $n_D = 2.06$. It is therefore improbable that the index of refraction

[1] Annalen der Physik und Chemie, 142: page 571, 1871.

should exceed 3. In Chapter XI it is, however, shown that there are other processes in play which would cause a slight color displacement in the prism experiment with increasing intensity of light. The second plate had, indeed, a stronger exposure than the first. Besides this, a small absolute error in determining the displacement would cause a larger one in the computation of the refractive index. The observations make no claim to great accuracy. They were not originally intended for the measurement of n_2, but only to show the approximate amount of the color displacement.

The magnitude of the displacement rendered it probable that it could be observed in air without the use of a prism by simply changing the angle of incidence. Indeed, in the case of the second plate, a shifting of the middle of the bright strip in the sodium flame, amounting to 0.36 millimeters, was observed on changing the angle of incidence from 0° to 45°, from which it follows that $f_1 = 0.98$.

But f_1 may be calculated from n_1 and n_2 by equation (1), if one substitutes for n_2 the the above-mentioned value 3.1. In this way f_1 is found to be 0.97, which agrees with the value observed within the limits of experimental error.

The possibility of the recognition of a color change with a wave-length relation 0.98 permits the determination of the limits of the safe application of the prism experiment. The question arises, How great the index of refraction of a film may be and still permit the recognition of interference colors in it by the use of a prism? If one compares the color at direct incidence in air with that at 45° in the prism, we have substituting $n_1 = 1.75$ and $f_p = 0.98$ in equation (2): $n_2 = 6.2$. If the comparison is restricted to 45° incidence in both air and prism, it follows with $f_{pl} = 0.98$ by equation (3): $n_2 = 5.2$.

So far as I know there have been no greater indices of refraction than this observed for the D line. That of molecular silver is, according to Wernicke,[1] based on the computation of Drude,[2] equal to 4. Checking his calculation by the molecular refraction from the known refraction equivalents of a haloid and a haloid compound of silver, a value less than 3 is obtained.

Thus it is possible by the prism experiment, for example, to test the assumption recently made by Wernicke, that the colors of silver observed by Carey Lea are only interference phenomena of molecular silver. With $n_2 = 4$ and $n_1 = 1.75$, f_p becomes equal to 0.95; and thus a silver plate appearing in air golden yellow ($\lambda = 589\mu\mu$) should in the prism look distinctly greenish yellow ($\lambda = 560\mu\mu$). If such a color change is not to be observed, then a case of body colors is at hand, and Carey Lea was right is assuming particular modifications of silver.

Still more certainly can one distinguish between interference and body colors in any chlorine compounds intermediate between silver

[1] Wernicke, Annalen der Physik und Chemie, 52: page 527, 1894.

[2] Drude, ibid., 51: page 98, 1894.

chloride and pure silver. This is done in this research for the procedure of Becquerel. It must be equally possible to distinguish in the process of Seebeck, where chlorine compounds are also made use of.

I may here offer a remark concerning a conceivable improvement in color photography by the interference method. Lippmann's color reproductions have, to be sure, the advantage of the possibility of fixing and of greater sensitiveness to light over those of Becquerel. They are, however, inferior, in that the colors are more dependent on the angle of incidence and in the necessity of observing them in a definite beam of light. In Becquerel's method the colors are changed so little with the angle of incidence that it was not for a long time shown that any change at all occurred, and they can be observed in diffuse light. Thus these colors have the characteristics of body colors without being such. They receive this quality by reason of the high index of refraction of the film.

Lippmann's color reproductions would share in this advantage, and would, indeed, be suitable for copying on paper if it were possible to make some addition to the gelatine such as to give it a higher index of refraction or even to replace it by some other substance with such an index. It cannot, however, be said a *priori* whether this is possible without the loss of other advantages of the method.

VIII.—Becquerel's Color-Bearing Film viewed from the Back.—Second Proof for the Interference Nature of the Colors.

For the purpose of Chapter II it was necessary to separate the color-bearing film of the Becquerel plate from the silver backing. This was accomplished with gelatine according to the directions of Wernicke.[1]

In so doing I observed the remarkable phenomenon that the colors of the reverse side by reflected light were very considerably displaced from what they were originally when viewed from in front.

The tone of the colors was also somewhat changed. Such a change of color is not conceivable for body colors and can only be explained through interference. This observation furnishes, therefore, a second proof of the interference nature of the colors and at the same time of the correctness of Zenker's explanation of them by the assumption of stationary light waves.

Such color shifting has also been observed with Lippmann plates when examined from the glass and film sides. I can not, however, recognize the explanation which I found given for this as correct.

These phenomena are the necessary consequences of facts hitherto overlooked. It would nevertheless lead me too far from the subject of this investigation to discuss this matter here. I must reserve the consideration for another publication.

[1] Wernicke, Analen der Physik und Chemie, 30, page 462, 1887.

IX.—Prism Experiment with Seebeck's and Poitevin's Color Reproductions.—First Proof that they are of the Nature of Body Colors.

The prism experiment with Seebeck plates is beset with difficulties which delayed the present investigation very considerably. The silver chloride powder must be retained between two glass plates. It does not suffice to pour benzene between the cover plate and the prism in order to see the colors through the latter, for total reflection occurs at the boundary of the air space between the cover plate and the particles of powder. The air must therefore be completely expelled by a liquid of not too small index of refraction. Benzene was chosen for this purpose. The introduction of the benzene could not, however, take place after the exposure, for it was found impossible to do this without altering the position of the particles of powder. Hence the benzene was first poured between the plates and then the powder was stuffed in between them.

A square cornered metallic frame served to support the whole. Instead of glass, a mica plate about 0.08 mm. thick was used on the front side. It was thus possible to avoid a slight displacement of the reference mark with respect to the spectrum in the prism experiment.

The presence of the liquid did not interfere with the production of the colors by the action of light. These came as before, only more quickly, for by absorbing the free chlorine given off the liquid made the plate more sensitive, but this added considerably to the difficulty of the prism experiment, as the observation required to be quickly completed before the action of daylight obliterated the spectrum reproduction.

The experiment was finally repeatedly performed with success. The reference mark was drawn with a diamond in the red and blackened with soot. There was no perceptible displacement of colors with respect to it. At the same time it was worth while to secure greater certainty by a simple modification. For this purpose pure chloride-of-silver powder was stirred up with collodion and the mixture poured upon a glass plate and dried. There was thus obtained a film in which the chloride of silver was retained by collodion. It was then fixed to a glass plate. The reference mark was made with a lead pencil on the film itself and the prism experiment performed without possibility of error.

The plates in benzene could not be left long in the daylight. The room was therefore darkened and light was admitted through a hole covered by a double layer of filter paper. The new process had, however, the advantage that the colors appeared more distinctly. Under the prism they were, to be sure, darker; but the result was repeatedly reached with certainty that no displacement of the colors in the prism with respect to those in air occurred for an unbended reference mark.

No difference in this respect was found between the coarse-grained

layer of the silver chloride-collodion mixture and the fine-grained liquid emulsion. The diameter of the grains was in the latter case determined by the microscope to be about 0.001 mm.

Regular stationary light waves are impossible in such grains. The motion of light among them must be very irregular. This is the case also in a still higher degree with the Poitevin films on paper. The fact that they reproduce colors much better determined me to subject them also to the prism experiment.

It was found undesirable to have the benzene soak through the whole paper, because the colors were thus made less distinct in air. The spectrum reproduction was therefore cut in half perpendicularly to the reference mark after drawing the latter in the yellow. One of the parts was placed upon the side of an auxiliary prism II (Fig. 3 shows section of the prisms and leaf), and this was fastened to a level glass plate, upon which the other half of the leaf was so placed that the marks came together. Finally prism I, with the high refractive index, was set upon the second half, benzene poured between, and the eye placed in line with the reference mark and with the surface of the principal prism. It was noticed that the colors under the prism

FIG. 3.

were a little less bright and the green and blue a little less distinct This was due to the yellow coloring of the flint-glass prism, for a line drawn on paper with a blue pencil appeared of a greenish tone through the prism. A displacement of colors could not, however, be observed through the prism.

The sensitive substance in Seebeck's process is the same as in Becquerel's. In Poitevin's method other constituents are used, which probably only lower the index of refraction of the layer. The absence of color displacement shows that the colors of Seebeck and Poitevin pictures are, in distinction from those of Becquerel, not interference but body colors.

X.—SEEBECK'S AND POITEVINS' COLOR PICTURES OBSERVED IN TRANSMITTED LIGHT.—SECOND PROOF OF THEIR CHARACTER AS BODY COLORS.

The films prepared from collodion emulsion of chloride of silver according to Poitevin's process show colors after exposure to the spectrum illumination when observed from behind, both in reflected and transmitted light. These colors correspond in position with those

appearing on the front surface. In transmitted light they appear in part even more distinctly.

This is a second proof that the colors are body colors, that is to say, produced by absorption.

This observation has been repeatedly made by other investigators, but I have never yet found the conclusion drawn from it with regard to the nature of the colors. Perhaps this is due to a fundamental error which Zenker, the founder of the interference theory of color photography, made in this connection. In his treatise on photochromie he says, on page 81, in reference to the color reproductions through the formation of stationary light waves:

> Similarly, it is natural that the same colors should appear by transmitted light that are observed by reflection, for since the transmitted light is certainly not the direct continuation of the incident ray, but at least in part also experiences several reflections, those same colors must preponderate in it that correspond to the distances apart of the point layers, that is, colors identical with those in the ray ordinarily reflected.

By point layers are meant the elementary mirrors which are formed in the sensitive film by the action of the stationary light waves.

The colors, however, which are due to reflections from the elementary mirrors must be complementary to the reflected colors at the same parts of the plate as in all pure interference colors, for they must together make up the incident white light. They can indeed not fail of this, for by hypothesis they are produced wholly by interference and not by absorption.

If one inquires how in the same difference of path, that is the double distance between two neighboring elementary mirrors, different interference colors can be produced in reflected and transmitted light, he forgets the phase changes occurring in reflection. At the same geometrical plane where a ray of reflected light at the first elementary mirror is thrown back in passing into optically *denser* or rarer parts, respectively, the transmitted and twice-reflected ray is thrown back in passing into optically *rarer* or denser parts, respectively, and receives, therefore, an opposite phase change. That at the second mirror is in both cases similar. Thus there remains a phase difference of a half-wave length, which causes the complementary coloring of the transmitted light. There is no change in this relation with a greater number of reflections. It may be objected that the phase change on reflection at an elementary mirror must be the same, whichever side the light falls upon it. That is the case; but it must be remembered that the elementary mirror is not a geometrical plane, but a layer of finite thickness. Otherwise it could not, in the absence of absorption, reflect light.

Exactly this objection aids in determining the phase change on reflection at an elementary mirror and not at a geometrical plane coincident with its boundary or within, as was discussed above. Since in transmitted light the twice-reflected ray experiences, with reference

to that passing directly, a phase change of a half wave length, and since at each of the two elementary mirrors it receives the same phase change, the phase change on reflection at an elementary mirror is one-fourth wave length. In this the phase change is reckoned with reference to a ray reflected without phase change from the plane at the middle of the elementary mirror.

The result above described will be deduced in another way in the connection mentioned on page 184, and difficulties and objections encountered will also be discussed.

All that has just been said concerns the case when there is no absorption. Such a case is furnished by the chrom-gelatin process of Lippmann,[1] in which the transmitted colors are complementary to those reflected.

When absorption is present it would readily be decisive in the case of transmitted light, because each complementary transmission color, as in the colors of thin plates, must contain much white light and be therefore faint.

Thus Krone[2] was able to observe only the characteristic color of the precipitate formed by development in Lippmann's haloid-silver plates by transmitted light, and I have myself made the same observation. Lippmann himself says that in two silver bromide-albumin plates he observed complementary colors transmitted.[3] The absorption must in this case have been very slight.

Where the same colors appear by transmitted as by reflected light, these can not be due to interference, but must be caused by absorption. Conversely, absorption, when it is not too strong to show surface colors, must show the same colors by transmitted as by reflected light, for this is nothing but doubly transmitted light.

We have thus a second proof that the colors in Seebeck's and Poitevin's processes are body colors.

XI.—The Cooperation of Body Colors in Becquerel's Process.

I remarked in the general survey (I) that it would be astonishing if Seebeck's plates showed body colors under colored illumination and the plates of Becquerel, which chemically are almost identical, failed to show them. It was, however, to be expected that these body colors would be hard to recognize so long as interference colors were very strong. It is not difficult to suppose that these latter would be weakened by a long time of exposure, in consequence of which the photographic action must penetrate very close to the vibration nodes of the stationary waves. This result was observed by Krone[4] with Lippman's

[1] Lippmann. Comptes rendus, 115: p. 575, 1892.
[2] Krone. Darstellung der natürlichen Farben, p. 54.
[3] Lippmann. Comptes rendus, 114: p. 962, 1892.
[4] Krone. Deutsche Phographen Zeitung, p. 187, 1892, edited by Valenta.

process. Sufficiently overexposed portions of the spectrum were white. Becquerel[1] himself says of his process that the differences of color disappear with prolonged exposure.

I have, therefore, exposed a Becquerel plate twenty hours, and a second thirty hours, to illumination by the spectrum. The prism experiment then gave, with the first, a slight color displacement; but with the second the displacement was hardly noticeable. At the same time the colors were very indistinct under the prism.

A more thorough demonstration of body colors was to be expected in examining the color-bearing film by transmitted light. The film was for this purpose removed from the silver backing (see p. 184). There then appeared *in reality*, by transmitted light, red and a trace of blue in the proper places, the latter, however, being in the first plate more of a grayish blue, and in the second of a violet-blue tone.

It was, however, to be expected that interference colors would exert a disturbing action. Hence, the side which had been next the silver, and which showed brilliant interference colors by reflected light, was rubbed with a leather pad till these colors were fainter. The red, in particular, was now transmitted much more strongly, but it was no more a spectrum red than in Seebeck's process. The same was to be observed in a film exposed only three-quarters of an hour, but less distinctly.

These experiments show, therefore, that in Becquerel's plates, also, body colors are produced and cooperate to a greater extent the longer the exposure is continued.

XII.—The Theoretical Basis of a Method of Color Photography with Body Colors.

In order that a substance sensitive to light can be chemically changed by the action of any kind of light it must absorb it. The converse proposition is not general. The absorbed light can, for example, be exclusively transformed into heat. A distinction is therefore made between thermal and chemical absorption of light.

For the sake of simplicity of expression I shall designate as a regularly absorbing light-sensitive substance one which is sensitive to all colors which it absorbs, and is affected by each color in proportion to the capacity for absorption. That there are such substances, at least to a considerable degree of approximation, is known. Upon their existence is based the important law of optical sensitizers established by H. W. Vogel.[2]

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[1] Becquerel. La Lumiere 2, p. 222, 1868.

[2] The maximum of sensitiveness is, with respect to the absorption maximum, thus far continually found to be displaced toward the less refrangible end of the spectrum. The displacement of these maxima on the same plates has been investigated for a great number of sensitizers by J. J. Acworth (Annal. der Phys. und Chem., 42, p. 371, 1891). He finds not only great but also very small displacements. It is, then, not impossible that there may be color substances in which the displacement is not noticeable for the purpose under consideration.

It is conceivable that the regularly absorbing light-sensitive substance may be decomposed by the action of light to form colored substances also regularly absorbing and light-sensitive.

I will designate as a color-receptive substance a black regularly absorbing light-sensitive substance, whose products of decomposition consist only of monochromatic regularly absorbing light-sensitive substances of at least three radically different colors, and, besides these, of a white substance which, however, is the least readily formed. These colors must be radically different in order that by their mixture with one another and with white all compound colors may be possible. In distinction from these compound colors the unmixed colors will be called ground colors. The monochromatic substances reflect only one color well. They must absorb the others the more completely the more they differ from them. With these preliminaries it may be shown that a color-receptive substance reproduces the color of the illumination correctly.

First, let the color of illumination agree with a ground color. It will be absorbed by the black body and produces a decomposition substance which, by hypothesis, is regularly absorbing and light-sensitive. In this decomposition different colored substances are formed. Those not agreeing in color with the incident light, absorb it, since, by the hypothesis, they are monochromatic, and must absorb all illumination different from their color. Since these are regularly absorbing light-sensitive substances, they are also decomposed by the light which they absorb. On the other hand, the substance of the same color as the incident light is not decomposed, since it does not absorb. In the end, therefore, it alone can remain in company with the white substance. The amount of the latter is, by hypothesis, very slight, and its effect upon the color is therefore noticeable only under strong illumination.

Where the color of the illumination differs from that of a ground color, but is intermediate between two ground colors—as would, for example, be the case with green, were yellow and blue ground colors—the colored substances would suffer least decomposition which reflect green best, that is, the yellow and blue. A green mixture would thus arise besides the small quantity of white.

In white light all the color substances would be decomposed, leaving white alone.

In the absence of illumination, the substance would remain black.

It may thus be seen that all colors would be correctly reproduced. The duration or intensity of the exposure must, however, be properly limited; for, if carried too far, white would begin to predominate, and the colors must gradually be extinguished.

It is possible that a light-sensitive substance should have only partially color-receptive qualities. Such an one would reproduce colors but partially. If the substance is not black, then black could not be reproduced. If not a regularly absorbing light-sensitive substance, it

would remain unchanged for some color which it absorbs, and hence can not reproduce this. If the ground colors are not monochromatic, the monochromatic illumination which such an one reflects would either be mainly incorrect or inaccurate in tone. Such an error is introduced, also, if the products of decomposition are not regularly absorbing and light-sensitive. Finally, if less than three products of decomposition result, or if their colors are not radically different, not all colors can be reproduced. This remark has reference, also, to the white product of decomposition. In its absence white can not be reproduced.

In spite of all such deviations, any light-sensitive substance which yields colored decomposition products will reproduce colors to a certain extent; for the colored illumination will leave similarly colored compounds unaltered, since they reflect the light, and will, on the other hand, decompose other colored substances more readily, since they absorb it.

It will be thought that the properties of a color-receptive substance are very complicated and difficult to attain. Nevertheless, this complication is afforded by known natural processes. It is, however, not necessary, for if it is sought to attain color photography by body colors in the simplest way, it is possible to make a selection of the absorbed light which produces decomposition. I will return to this in Chapter XIV.

XIII.—Explanation of the Color Reproduction in Seebeck's and Poitevin's Processes.

The color reproduction is explained by the fact that the light-sensitive substances used possess to a certain degree of approximation the qualities of a light-receptive substance; not completely, for the color reproduction is not complete.

The first deviation consists in that the light-sensitive substance is not black, but in Seebeck's process dark violet to gray violet, in Poitevin's a dark gray violet to gray brown. Black can therefore not be reproduced, and in its place occur the above-mentioned dark hues. Nevertheless, these substances share with black the characteristic that they absorb all visible rays to a certain measure and are light sensitive to all. The products of decomposition are, as remarked in Chapter I, substances of different colors. They must be, according to the results of Carey Lea and Krone, either very numerous or very different in color. But they are not absolutely monochromatic, and in this is to be found the reason why the reproduction of color tones is partially incorrect. (See Chapter IV.)

A white product of decomposition is not present in Seebeck's process, hence white can not be thus reproduced.

In Poitevin's process white can be reproduced. The tendency to the production of white is, however, less than that for the other decomposition products, and the colors are made pale only after long exposure.

It remains now to see for each of these processes whether the decomposition products are regularly absorbing light-sensitive substances. That this is the case only in a measure is shown by the degree of accuracy of the color reproduction.

In Seebeck's process the red is the most distinct. In order that it can be produced with red illumination all the other decomposition colors must be red sensitive so that they may be decomposed by red. This is the case.

As a test the result of an exposure to illumination by the spectrum was turned in its plane through 90° so that each color of the picture was exposed to the illumination of the whole spectrum. The red of the first exposure was the only color remaining unchanged under the red of the second exposure. All the other colors were destroyed and the plate took on a red coloring to the borders of the ultra violet.

The other colors behaved similarly, but as they were not so well marked as the red after the first exposure, so after the second they were even less distinct. It may, however, be said that the red produced by the first exposure was destroyed by the green and blue of the second, though the lightening up of the ground tone in connection with the red still remained. This agrees with the experiment of Carey Lea, mentioned on page 172. The green of the first was destroyed by the blue as well as by the red of the second. The blue of the second exposure destroyed, therefore, both the red and green resulting from the first. Violet could naturally do the same, as blue is produced from the violet ground color. Since now yellow is scarcely at all reproduced in this process, the formation of blue by the action of blue light is explained from the fact that it is able to alter all other decomposition products. Blue is, indeed, after red, the most satisfactorily reproduced.

In Poitevin's process the colors are better marked, and the experiment with crossed spectra was therefore more satisfactorily performed.

In one experiment the exposures were each continued a half hour. The colors of the first picture remained, as was expected, unchanged where the same colors fell upon them in the second exposure. Under different colored illumination they were changed according to the observation of Dr. Holzapfel in the following manner: The red in the first picture was in the yellow of the second illumination yellow, and under the other kinds of illumination correspondingly altered.

The yellow of the first picture was unchanged by the red of the second illumination, was changed a little by the green, was greenish in the blue, and was in the violet destroyed.

The green of the first picture was changed to red under the red of the second illumination, was yellow under yellow, and remained unchanged under blue and violet.

The blue of the first picture was made red under the red of the second illumination, yellow under yellow, green under green, and was in the violet altered and darker.

The dark violet which was produced by the violet of the first illumination was made red by the red of the second, and under other colors took on a rather indistinct color, which, however, inclined toward theirs.

In general, then, each colored substance remained unchanged under similar illumination and was under different illumination altered or destroyed. An exception to this rule occurred in the case of the yellow, or rather orange, as the color produced by pure yellow illumination appeared of a more orange color (see page 177). This color was not changed by the illumination of the neighboring red and green, and was not easily altered by the blue, since in this case the mixed color, green, resulted.

These facts would contradict the explanation of the color reproduction given if there were not a cause for failure which justifies the explanation; if, namely, the orange colored substance is not completely light-sensitive for red and green it can exist at the same time with red under red and with green under green illumination, without being again decomposed. If, however, this substance is the more stable under the action of light, it will finally gain the ascendancy, and this was in fact observed.

The originally narrow orange yellow strip broadened out in both directions with increasing duration of exposure. Its breadth was, for example, in a field exposed 24 minutes about 1 millimeter and in one exposed five times as long 3 millimeters. This broadening was in some experiments more considerable toward the red than toward the blue part of the spectrum. In other experiments this appeared not to be the case. This may have been due to slight differences in the method of preparation of the sensitive film.

The fact that this displacement takes place agrees well with the following phenomenon. An exact investigation showed, namely, that in short exposures, for example 4 minutes, a red and not a yellow color results from illumination with sodium light, which gradually takes on the orange coloring. It therefore appears that the yellow substance is a product of the decomposition of the red. This process must be explained chemically, and need be taken in consideration in the present investigation only as explaining the one-sided displacement of the orange yellow strip with increasing time of exposure. For, in accordance with what has been said, the red preliminary product would more readily be produced by red than by green illumination.

It must be observed that the deviations of the characteristics of the photographic substances in use from those of color-receptive substances lead to deviations from a correct reproduction of colors. For that color in Poitevin's process, however, which with prolonged exposure is continually correctly reproduced—namely, orange yellow—the conditions are fulfilled. All other colored substances produced are sensitive to orange-yellow light, and are decomposed by it.

The color reproduction by the substances used by Seebeck and Poitevin and the degree of its accuracy are therefore explained by the fact that they possess the characteristics of a color-sensitive substance as approximately as is required by the degree of accuracy of the color reproduction.

XIV.—The Standing of Color Photography with Body Colors with reference to the Color Printing and Interference Processes—Possibility of the Perfection of Color Photography.

Color photography with the aid of color-receptive substances will be here distinguished as body-color photography.

It resembles the process recently worked out by H. W. Vogel[1] of color printing in so far that the colors in both cases are reproduced by body colors. Both methods require also the presence of regularly absorbing light-sensitive substances, which admit of the application of the Vogel fundamental law of optical sensitizers. Progress in the discovery of such substances will be advantageous for both processes.

The methods employing body colors lend themselves the more readily to reproduction of pictures, since the colors appear by transmitted light. For this purpose it would be necessary to use transparent plates, such as have been of late employed by Veress.[2] The color-printing process naturally has the advantage over all others in the capacity for reproductions. But the method employing body colors is at least superior to the interference process in this respect.

This method more resembles the interference process, however, in that the colors are directly produced by the illumination. Since the resulting colors are, moreover, not apparent, but real body colors this process may perhaps be looked upon as promising the ideal of color photography. Its results are, to be sure, at present far removed from the ideal, but perhaps this will be otherwise after the recognition of the foundation upon which the process rests.

The Seebeck and Poitevin processes choose a roundabout way. The properties of a color-receptive substance are very complicated. But after it is shown that such a substance reproduces colors correctly one can conversely base his considerations on the capacity for correct color reproduction, and pursue the inquiry, What are the simplest characteristics which are required for this purpose?

I believe that these are to be found in a black mixture of three regularly absorbing light-sensitive substances which decompose with the formation of white products. To be sure, however, the greatest variety in this process is conceivable.

There are different ways which may be imagined in which fixing

[1] Verh. der phys. Ges. z. Berlin. Ann. der Physik und Chemie, 46, page 521, 1892.
[2] See Elder's Jahrbuch für Photographie, page 46, 1891.

can be secured. It appears not impossible that the color substances produced should by chemical action be converted into similarly colored stable substances, or by a suitable addition be protected from decomposition. A case of the latter kind is mentioned by Otto N. Witt in a very excellent memoir.[1]

There are, he says, fading dyes—that is, light-sensitive substances—in threads which are made lasting by saturating the thread with copper salts. According to Witt's hypothesis these copper salts have no influence on the dyes, but on account of their easier decomposition absorb the light energy and make it harmless to the colors.

It is also conceivable that the photographic film might be made light sensitive by the addition of other substances and again become insensitive after their withdrawal. It may be asked what object there is in seeking for new processes when excellent ones are already at hand. Experience, however, shows that where there are different solutions of a technical problem it is seldom that any one supersedes all the others. Each retains that province for which it seems best adapted. And if the body-color processes are at present the most incomplete, the future investigators can not now be told within what limits these imperfections shall remain any more than future generations can be informed within what bounds their knowledge will be included, as is exampled by those who in times past have thought to determine such limits.

XV.—Mechanical Color Adaptation in Nature.

A far-reaching influence has been already ascribed to light in the production of the colors of nature,[2] not only in plants, whose green is attributed to the action of light by all, but also in animals. Such a direct influence is, however, generally denied, or at least only recognized in a restricted way, most scientists, with Darwin, attributing the coloring of animals to the action of natural and generic selection.

[1] Otto N. Witt, "Ueber Farben und Färben. Eine Studie über Energieverwandlung." Vortr. geh. bei Gelegenheit des VI. deutsch. Färbertages. Prometheus, pp. 625, 641. 1894. He remarks very significantly that theory and practice have ceased to be strangers to each other, since each theoretical advance is followed by one in practice. This is certainly true of the development of color photography, and it is to be hoped in the case at hand. I can not, however, leave unchallenged one statement of the author, namely, his assumption that the chemical action of the long wave lengths is possible only by their conversion, after absorption, into short waves. One might with equal justice say that the heating effects of short wave-length radiations are to be explained by their preliminary conversion into long. The nature of the action of light is, however, determined, not by the wave lengths, but by the characteristics of the receiving substance. My experiments with stationary light waves show that the chemical action is caused by indwelling electric forces, and these are, of course, independent of the wave length. They can, according to the nature of the receptive substance, produce either decomposition or heating, just as the electrical energy of a constant current may produce decomposition of electrolytes or heat in a metallic conductor.

[2] See Karl Semper, Die natürlichen Existenzbedingungen der Thiere, Leipzig, F. A. Brockhaus, 1880, page 107.

Without contradicting this action, Semper[1] has lately maintained that this explanation is not complete, and that, for example, the first appearance of coloring matter in the covering of an animal is unexplained. This remark can, of course, not refer to colors which are to be regarded as the insignificant characteristic of the chemical compounds produced by the organization. It has, on the other hand, reference to the general lack of color observed in animals which live in the dark.

Semper[2] and Eimer[3] remark that the change in forms of life which lies at the basis of Darwin's doctrine was taken by him simply as a fact, and that it still lacks detailed explanation. Eimer[4] regards as the causes of these variations the physical and chemical changes which are brought about by the action of exterior conditions on living beings. He attributes to the action of light a considerable influence on the formation and alteration of the colors of animals.[5]

In such considerations one enters the domain of physical conceptions, for such demand the regular procedure of an event with the simultaneously changing conditions. In contrast to a mechanical explanation of this sort those of Darwin are to be distinguished as statical, and take somewhat the same relative position with regard to it that the explanation of the gas law by the kinetic theory of gases bears to the purely mechanical explanation of the motion of the separate molecules. The standpoint of observation in the two cases is, however, different. For gases we consider a phenomenon as a whole, while in nature it is generally the single items. I go into these general observations to show that the two kinds of explanation do not exclude each other, but on the other hand are complimentary.

In this connection the establishment of the direct action of light on the colors of animals deserves particular attention. Such an action has been thoroughly investigated for caterpillars and butterfly pupæ. It was discovered by T. W. Wood[6] in the year 1867. The caterpillars inclosed in chrysalises were brought into the sunshine and surrounded by colored substances. They took the color of these surroundings. How extensive this receptivity of pupæ and caterpillars is has lately been shown by the extraordinarily thorough and careful experimental investigations of Edward B. Poulton.[7]

[1] Semper, loc. cit., page 122.

[2] Semper, loc. cit., preface.

[3] Eimer, Entstehung der Arten, 1: page 1.

[4] Loc. cit., page 24.

[5] Loc. cit., pages 93, 145, 167, et al.

[6] T. W. Wood. Proc. Ent. Soc., pages 99–101. 1867. Cited by E. B. Poulton, "The Colours of Animals," London, Kegan Paul, Trench, Trübner and Co., 1890, who himself has described the history of the discovery, page 113 ff. See also Poulton, Phil. Trans., London, 178: page 312. 1887.

[7] See besides the above-mentioned writings the comprehensive treatise, "Further experiments upon the colour relation between certain lepidopterous larvæ, pupæ, cocoons, and imagines and their surroundings." Transactions of the Entomological Society of London, page 293. 1892.

Wood, the discoverer, assumed as the cause of the phenomenon a photographic sensitiveness of the skin, but gave no proof. His assumption was not, however, completely self-evident; for there are cases of quick color adaptation known which rest upon other grounds, as, for example, among frogs and fishes. In these animals the color adaptation is dependent on sight. If they lose the use of their eyes,[1] be it at the instance of the experimentor or accidentally, they lose their capacity for color adaptation. This rests, however, not upon a change, but only on a different arrangement of the coloring matter through the shrinking together of the color-bearing cells or so-called chromatophores (?), which lend to the chameleon[2] the remarkable capacity for color changing.

Upon these grounds Poulton thought it desirable to seek, first of all, for a similar connection in the case of caterpillars. He covered the eyes of a number of caterpillars with an opaque screen.[3] They did not, however, lose the capacity for color adaptation.

His attention was then directed to the hairy spines[4] of the caterpillars under investigation, to see if they perhaps might hide some light-sensitive organ. But this supposition proved erroneous. The shorn caterpillars retained their capacity for color adaptation.

The skin must therefore contain these organs. Poulton[5] investigated the physical constitution of the coloring in *Amphidasis belutaria*, the birch-moth, which possesses this color receptivity to a high degree. This moth owes the green color to a coloring matter contained in oil cells in the fatty layer which lies between the epidermis and the surface muscles. The epidermis itself may also secrete a dark coloring matter, which then hides the green pigment and makes the skin appear brown.

The different colorings are here formed, therefore, not by different layers of unchangeable color substances, but through the formation of new coloring matter and its alteration under the action of light. The most effective changes take place in the dark cells in the epidermis, but the green lying beneath is influenced. The range of colors thus possible runs from brown, green, and gray on the one side to black and on the other to white.[6]

If, now, the color adaptation of caterpillars is connected with the color reproduction in body color photography, the dark coloring matter must be formed in the dark and the lighter colors result from the action of light upon it. Poulton, indeed, observed that in the dark, dark-colored caterpillars and pupæ were formed by preference, while the

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[1] Experiments and observations of Lister and Pouchet. See Semper, loc. cit., page 117; Poulton, Colours of Animals, page 85.

[2] See Ernst Brücke, Untersuchungen über den Farbenwechsel des Afrikanischen Chamäleons. 1851 and 1852. Ostwald's Klassiker, 43.

[3] Poulton, Phil. Trans., 178: pages 323, 345 ff. 1887; Colours of Animals, page 128.

[4] Poulton, Phil. Trans., 178: page 335, 1887; Colours of Animals, page 128.

[5] Poulton. Trans. Ent. Soc., page 357. 1892.

[6] Poulton. Trans. Ent. Soc., page 359. 1892

brighter colors came about in the light.[1] It is worth noting that dark surroundings in a bright light brought out somewhat lighter dark forms than complete darkness.[2] I will return to this point.

How far the above-described characteristics of a color-receptive body must be assumed for the coloring matter of the skin of caterpillars, in explanation of their color adaptation, depends on the extent of this adaptation. This question is connected with the other, whether the caterpillars are restricted in their adaptation to colors which they might meet with in nature, or if they can take on also others. Poulton[3] has in general observed only the first case. But he has showed that it is not peculiar situations but the light which exerts the influence; for not only were green leaves and brown twigs effective, but also green and brown strips of paper. White strips of paper and different colored glass windows were similarly active.[4]

If, however, caterpillars are able to take on other colors than those of their natural surroundings, these could not be looked upon as protection colors. An explanation of this kind was rejected by Poulton in the cases of *Pieris brassicæ* and *Pieris rapæ*, which changed into pupæ in a glass cylinder two-thirds covered with orange-colored paper. This color destroyed the dark coloring matter more than any other except white and gave rise to bright yellowish-green pupæ.

A pronounced deviation from natural colors is mentioned by Beddard, who says:[5] "Mr. Morris[6] succeeded in producing white, red, salmon, black, and blue pupæ of *Danais chrysippus;* they are only green or pink in nature." It must therefore be assumed that the coloring matter of these caterpillars possesses in a high degree the characteristics of a color-receptive substance, as already defined.

From these examples it follows that the biological explanation of protection coloring is not satisfactory; but it in no way follows that natural selection was not in play in the production of the color-receptive pigments of the caterpillars. For it is easily possible that if these are capable of reproducing the natural colors of the surroundings, they also with the same chemical constitution have the capacity of reproducing other colors.

The assumption that this constitution possesses, in some measure, the characteristics of a color-receptive substance is confirmed by another experiment of Poulton. Since the caterpillar's skin could readily assume the color of leaf-green, the light of this color must be particularly active in decomposing the dark pigment that is secreted in the skin in the absence of light. Poulton investigated, in the case of *Pieris*

[1] See, for example, Poulton, Phil. Trans., 178: page 430, 1887; and Trans. Ent. Soc., pages 328, 353, 1892.

[2] Poulton. Trans. Ent. Soc., pages 329, 385. 1892.

[3] Poulton. Trans. Ent. Soc., page 470. 1892.

[4] Poulton. Trans. Ent. Soc. See for example tables, pages 461, 466. 1892.

[5] Frank E. Beddard. Animal Coloration. London: Swan, Sonnenschein & Co., page 137. 1895.

[6] Morris. Journ. Bombay Nat. Hist. Soc., 1890, according to Beddard.

brassicæ and of *Pieris rapæ*, what radiations of the spectrum are most active in decomposing the dark pigment of the epidermis. The results were exhibited in a plot[1] whose abscissæ corresponded to the color of the illumination and whose ordinates gave the estimated degree of attack upon the dark coloring matter of the epidermis. Besides the already-mentioned maximum of decomposition by the action of orange-colored light of wave length between 570 and 650 $\mu\mu$, he found in the case of *Pieris rapæ* a second, though less marked for bright-green light with wave lengths between 510 and 584 $\mu\mu$. It is particularly the yellow constituent of the light sent out by green leaves which is able to destroy the dark coloring matter most effectually. The extreme red and blue portions of the spectrum are scarcely more active than darkness.

The similarity with the processes of poly-color photography goes even further. In the epidermis of green caterpillars of *Amphidasis betularia*, which is able to secrete the dark coloring matter, Poulton found instead of this a pale yellow coloring matter, which had a greenish-yellow appearance under the microscope. "It is therefore clear that the surroundings determine not only the presence or absence of true pigment in the epidermic cells, but also its constitution, and therefore color when present."[2]

The green coloring matter in the fatty layer can be partially destroyed,[2] for example, in white light. Therefore, it also receives rays which it absorbs and therefore act upon it.

A test of the explanation given is formed for color photography by the crossed spectra experiment. Poulton arranged a similar experiment. He moved caterpillars from dark to light surroundings, and vice versa, an experiment which he designates "transference experiment."[3] He found that a change of the first color in a sense such as to cause it to approach the second was to be noticed so long as it was confined to the time during which the caterpillar was sensitive. Here, however, occurs a great difficulty to the understanding of the phenomenon, which I must mention in detail.

It must first of all be remarked that in the previously mentioned phenomena of the skin of caterpillars it appeared as if it secreted a coloring matter which in the periods of sensitiveness possessed in some degree the character of a color-receptive substance. But in order that it could be said that the caterpillar's skin behaved like a photographic plate, it must be shown that two different parts of the skin which were subjected to different colored illumination assumed different colors.

One such observation has been made, but it appears to be the only one. It was communicated by Mrs. Barber in a memoir which was laid before the Entomological Society of London by Darwin.[4] A pupa

[1] Poulton. Phil. Trans., 178, fig. 6, page 431. 1887.

[2] Poulton. Trans. Ent. Soc., page 359. 1892.

[3] See for example Trans. Ent. Soc., pages 352, 419. 1892.

[4] Ent. Soc. Trans., page 519. 1874, according to Poulton.

of *Papelis nireus* was situated before coming out of the cocoon upon wood which lay next to brick. After shedding the skin its lower side took on the color of the wood on which it lay, while the upper was of the color of the brick. Poulton[1] remarks, on the other hand, that a difference between the color of the back and of the abdomen is frequently to be observed in pupæ. Yet this may perhaps be attributed to the fact that these surfaces are usually subjected to different illumination.

The experiments of Poulton led, however, to a contrary conclusion. He arranged so that the front and rear portions of a caterpillar should be differently illuminated, an experiment which he designates as the "conflicting color experiment."[2] No local coloring was distinguished, but a uniform average color over the whole body, which depended on the relative surfaces of the two parts, and without a preponderating influence being exerted by the front part.

The experiment of Poulton by which he established the facts of states of greater sensibility also speaks against the simple nature of the process. These periods occur at the time of changing into pupæ. In the "Transference Experiments" the change of surroundings occurred shortly before such changes, and in spite of this the first surroundings usually appeared more influential than the second upon the coloring which the caterpillar assumed after the changing into the pupa. The second skin is, of course, formed beneath the first and according to Poulton possesses no coloring matter. The future coloring of this skin is therefore influenced before it possesses coloring matter.[3] One must agree with Poulton when he rejects for these cases the assumption of a simple photographic process and supposes complicated physiological causes.[4]

In spite of this I do not regard it as impossible that a relation to color photography exists in so far that the coloring matter of caterpillars possesses the characteristics of a color-receptive substance to a certain degree. Naturally Poulton could not assume such a relation, for the basis of color photography was not then determined. There was for him, therefore, a break in the understanding of the color adaptation of caterpillars, which he expresses as follows:

"Some quality in the light reflected from surrounding objects forms the cause, but the physiological chain which connects the two [color of illumination and of the skin] has yet to be discovered."

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[1] Poulton. Phil. Trans., 178: page 315. 1887.

[2] See, for example, Phil. Trans., 178: page 373. 1887; Colors of Animals, page 131; Trans. Ent. Soc., pages 420, 446. 1892.

[3] I have to thank the kindness of the lepidopterologist connected with the institution, Mr. Omar Wackerzapp, for informing me that the caterpillars of *Geometra remaria* change from green in summer to brown with the dying of the leaves, and in the next spring return again to their former green color. In neither case, however, is there a change of skin in connection with the color change. See Stetl. Entom. Zeit., page 1, 1889. It is, however, not established that the light is here the cause of the change.

[4] Poulton. Phil. Trans., 178: page 317, 1887; Trans. Ent. Soc., page 391. 1892.

The relation sought is probably the ineffectiveness of light when reflected and its activity when absorbed, so far as color adaptation is concerned, which depend on whether it agrees in color with the substance on which it falls or not.

In order to show that the remarkable influencing of the condition of the future skin and the effect of the illumination of a part of the skin are not in contradiction to this supposition, I must remark that processes are conceivable which are set up in connection with the commencement of the light absorption.

Poulton thought it possible that the surface colored layer is in a state of "complete physiological unity,"[1] and that the nerve system conducted the light action. It is not difficult to build up from this an accurate physical conception. I recall phenomena which Ostwald[2] has classed under the name of chemical actions at a distance. Amalgamated zinc can be dissolved by dilute acids acting not directly on the zinc but on a platinum wire which is placed in metallic contact with the zinc, but when the zinc and platinum are separated by a clay cell and the former dipped in a neutral solution. This action is, of course, by means of an electrical current.

In a similar way the illumination of the coloring matter of a cell may set up electrical currents in the nerve conductors which cause similar decomposition in other cells of the caterpillar's skin, such action being accompanied, of course, by a diminution of intensity of action in the exposed cells. In this way there would be caused a uniform change over the whole body. Such a transference of action may be compared with an apparatus to see things occurring at a distance or an arrangement to electrically photograph objects far removed.

Since, according to Poulton, not only the illuminated skin, but the colorless skin lying beneath it, is influenced, it must be assumed that in some way the decomposition is transferred to this latter, with the result of reversing the effect in the outer skin. This decomposition must hinder the later formation of coloring matter. Such peculiar conceptions are, to be sure, as yet premature, and are only made to show that the relation to color photography is not excluded. They are indeed complicated, but so is the process itself. Since nature proceeds from the simple to the complex it would be remarkable if cases should not yet be found in which the process remained at a less advanced stage of development and thus showed a direct relation to color photography.

Poulton[3] refers to similar processes the capacity of *Halias prasinana* to spin a cocoon agreeing in color with its surroundings.

The transferrence to a distance in caterpillars explains also the activity where dark surroundings are adjacent to light, for the parts

[1] Poulton. Trans. Ent. Soc., page 392. 1892.

[2] Ostwald. Zeits. für Phys. Chem., 9: page 540. 1892.

[3] Poulton. Trans. Ent. Soc., page 392, 1892; Colours of Animals, page 145.

of the skin lying in the dark are then places for the development of dark pigment, which is of use to the whole body. That this development is more rapid than in complete darkness and also more rapid for caterpillars which were first in light and then in darkness than for those always remaining in darkness,[1] is, perhaps, due to the action of the extreme violet and ultraviolet rays of the daylight. I shall later refer to a similar phenomenon in color photography.

Further cases of color adaptation have been above mentioned in which the eye receives the active impulse. According to Eimer[2] these cases are due to the possession by the caterpillars of a long nerve train extending between the place of reception of the stimulus and the place of its action, the place of reception of the stimulus being restricted to the eye. Semper[3] explains the color adaptation in these cases by the difference in intensity of action of certain colors and of brightness of the surroundings on the retina. These create, according to the observations of Dewar,[4] electrical currents of different strength, and thus one must attribute to them different capacity for attracting together of the chromatophores. With increasing strength of attraction the skin appears brighter. This explanation, it will be observed, is similar to that given for the caterpillars.

Semper[5] describes a remarkable observation, according to which "white rabbits breed most easily and surely in white reflected light." I scarcely believe, however, that this circumstance has to do with the subject under consideration. Their relatives in the far north are at least, with some reason,[6] supposed to put on their white winter garment through the influence of the cold. And if each rabbit received only reflected and not direct sunlight, they probably had their residence in a cool place.

I do not know whether the above-mentioned kind of color adaptation has an extensive application. Perhaps, however, further examples of it will be recognized when the attention of biologists is drawn to it.[7]

It is remarkable that in the strong light of the equatorial regions more dark than light forms have developed. Here also a connection with the light has been assumed. Thus Darwin[8] contrasts the dark coloring of many birds which inhabit the southern part of the United States of America with those of the north, and adds: "This appears to

[1] Trans. Ent. Soc., page 419, 1893.

[2] Eimer. Entstehung der Arten, page 156.

[3] Semper, loc. cit., page 119.

[4] Dewar. Nature 15, pages 433, 453, 1877.

[5] Semper, loc. cit., page 265.

[6] See Poulton. Colours of Animals, page 94 ff., 1890; Beddard, Animal coloration. page 76, 1895.

[7] I found later in Vogel's Handbuch der Photographie, 1: 4 Aufl., 1890, pages 57, 203, the remarkable observation of Herschel (Phil. Trans., page 189, 1842) that certain vegetable coloring matters are most strongly bleached by the colors complementary to them. It would be interesting to observe whether in living plants, for example, certain flowers had the capacity to assume the color of their illumination,

[8] Darwin. Abstammung des Menschen; German by V. Carus, 5 Aufl., page 253.

be the direct result of differences between the two regions in respect to temperature, light, etc."[1]

It must be taken into consideration that our judgment upon the degree of color adaptation is disturbed by the insensitiveness of our eyes to the extreme violet and the ultraviolet rays on the one hand and those of the infrared on the other. These cause, however, chiefly blackening and must, therefore, be avoided.[2]

In this connection the following experiment deserves consideration, which I performed with Poitevin plates. These were brighter when the ultraviolet rays were removed from the undecomposed electric light employed in illumination by an absorbing solution, and, on the other hand, darker when these were suffered to pass through unhindered. This is a consequence of the decomposition of the silver protochloride in the first instance and of its new formation in the second. In similar experiments I recognized the darkening effect of heating and the favorable changes induced by moisture.

Finally, there is at least to be recognized a relation between the color adaptation of caterpillars and color photography in so far that the caterpillars secrete a coloring matter which to a certain degree possesses the characteristics of a color-receptive substance. In this sense the color adaptation of a single caterpillar must be regarded as mechanical. This is, however, not in contradiction to the conception that the capacity is attained by biological adaptation in the sense of Darwin, for those individuals will be best protected whose pigment is most color receptive.

It can not easily be decided whether this capacity is developed by the action of light, according to Roux and Eimer,[3] or only by chance alterations of the protoplasm in the course of time, according to Weismann. It must, however, be remembered that there are no completely fast coloring matters, and that all would to a certain degree be color receptive. Thus the early ancestors of the caterpillars, while not possessing the color adaptation of the present representatives, would still be somewhat changed by light. According to Eimer, it must be supposed that this chemical change would not be without influence on the constitution of the protoplasm and of posterity, and thus their individual changes would receive a certain directing impluse. These changes would, therefore, not require an accidental impression. But even if Eimer's hypothesis should be untenable such an accidental impression would be regarded in a physical sense only as an example of the play of unknown processes which still require explanation.

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[1] Mr. O. Wackerzapp gave me the privilege of examining a series of butterflies in his rich collection for which the influence of the region, or the climate, as, for example, on the north and south sides of the Alps, or the elevation, was distinctly visible in the gradations of color. The else insignificant variations are scarcely to be understood except as they are to be ascribed as the effect of light, heat, and other impulses.

[2] Zenker. Photochromie, page 59.

[3] Roux and Eimer. See citations, pages 19, 21.

XVI.—Summary and Conclusion.

I had set before myself the task of determining the causes of the color reproduction in the older processes of color photography which, in their main features, were introduced by Seebeck, Becquerel, and Poitevin.

The explanation of Schults-Sellach, by disintegration colors, was, in the first place, shown to be erroneous.

A method was required for the discrimination of interference from body colors which appear in substances of high refractive indices. This was found in the employment of a right-angled glass prism, also of high refractive index, through which the colors to be investigated were observed.

By means of the alteration in color thus produced it was shown that the Becquerel picture upon an underlying silver mirror was chiefly produced by interference. Here, therefore, Zenker had correctly ascribed the cause of the color reproduction to the formation of stationary light waves.

In the pictures of Seebeck and Poitevin there was, on the contrary, no color change. They consist, therefore, of body colors, and Zenker's explanation finds here no application.

The fact that these pictures show the same colors by transmitted as by reflected light leads to the same conclusion.

It was shown that in Becquerel's pictures body colors cooperate in a slight degree.

The understanding of the formation of body colors was promoted for the Seebeck and Poitevin processes by the proof for these processes, respectively by Carey Lea and by Krone, that the substances present in the plates are capable of yielding compounds which embrace almost all the spectral colors, if not all their tones.

The explanation was, however, lacking why the color substances produced agreed in hue with the illumination-producing decomposition.

This explanation is found, that of all colored substances capable of being produced only those will be stable which agree in color most nearly with the incident light, since these will best reflect and least absorb it, and can therefore be least changed. Decomposition products of other colors, on the other hand, absorb this light and will be again decomposed.

A test of this explanation was made by throwing a spectrum at right angles on a color photograph of the spectrum. It was found, in fact, that a correctly-reproducible illuminating color was capable of decomposing all colors differing from it, but similar colors remained unchanged.

It is therefore fundamentally possible that colored illumination shall, in suitable substances, produce similar body colors.

I have designated such substances as color receptive.

This possibility and the recognition of its cause form a new basis for a kind of color photography which may be distinguished as body-color photography. The hope seems justified that upon this foundation there may be built up new processes superior to the old body-color processes in accuracy and fixedness of the pictures.

Color reproduction can be designated as color adaptation, for it consists in the perpetuity of color substances which best withstand the action of colored illumination—that is, of similarly colored substances.

This circumstance raises the question whether color adaptation can be produced in a similar way in nature, that is through a process of mechanical adaptation in contradistinction to biological adaptation, which according to Darwin results by natural selection of individuals.

Such a case is presented by the caterpillars and their pupæ and has been thoroughly investigated by Poulton. While his experiments show the presence of complicated physiological processes, yet they make the assumption plausible that the coloring matter of these animals within the sensitive stages of development possesses to a certain degree the characteristics of a color-receptive substance.

In this case the phenomenon would belong to a general group of phenomena discovered by Wilhelm Roux and classed under the title of functional adaptation.

I believe that with the above the work of the physicist in connection with mechanical color adaptation is chiefly finished, and it is now the function of the chemist and photographer, on the one hand, and of the biologist, on the other, to make the physical results practically useful.

PHYS. INST. D. TECHN. HOCHSCHULE AACHEN, *April 25, 1895.*

PRESENT STATUS OF THE TRANSMISSION AND DISTRIBUTION OF ELECTRICAL ENERGY.[1]

By LOUIS DUNCAN.

The industrial life of mankind is made up of two things—the transformation and distribution of material, and the transformation and distribution of energy. The raw material from mines and forests is changed to finished products and distributed among the people, while energy, obtained from water power, coal, or other sources, is changed from the potential energy of the water, or the energy of chemical combination, to mechanical power, heat, light, etc. Unless we can transmit this energy economically, we must transform it into the required form at the place where it is to be utilized. At present a large part of our mechanical power is obtained from steam plants situated in the factories themselves, and for heat and light we mainly depend upon stoves and lamps in our houses.

Before the introduction of electrical transmission it was possible to distribute energy to limited distances by various methods, but no system offered a long-distance transmission for all purposes. By means of compressed air or steam pipes the energy of coal has been transmitted to produce mechanical power or for heating, and gas mains have allowed the distribution of gas for lighting or for fuel.

In the case of power obtained from steam plants the economy incidental to large units and a steady load has led to the concentration of industries. Where steam is used, the plants are situated where it is most convenient for manufacture; where water power is employed, it is necessary to bring the factories to the location of the power, irrespective of other conditions.

By means of dynamo-electric machines, the energy obtained from either coal or water power may be transformed into electrical energy; may be distributed and then transformed again into mechanical power, light, or heat, or may be used for a number of purposes peculiar to this form of energy alone. The limits to the distance of this distribution are imposed by conditions of economy and safety.

[1]Inaugural address of the president at the 108th meeting of the institute, New York, September 23, 1896. Vice-President Steinmetz in the chair. Printed in Transactions of the American Institute of Electrical Engineers, Vol. XIII, Nos. 8 and 9, 1896.

It is my purpose to take up the different methods of transmission and distribution and to consider the limits that are actually fixed by the present status of electrical development. The question is a commercial one, each problem presenting different conditions which must be considered, but certain general principles govern each case, and our knowledge and experience makes it possible to judge the practicability of each particular transmission.

GENERATING PLANTS.

At the present time practically all of the electrical energy distributed is generated in plants operated either by steam or water power, and it is important to consider the conditions of maximum economy in large generating plants, as this bears directly on the subject of transmission and distribution.

A large proportion of the electrical plants in this country are steam plants. In the last ten years we have advanced from small stations using high-speed dynamos for light and power distribution to large stations, using, as a rule, low-speed direct-connected machines. The simple engines that were used some years ago have in many cases been changed to compound and even triple expansion engines, and where it is possible condensers have been employed. Some of the latest plants have machinery of the highest possible efficiency, and yet if we consider the price per horsepower of the power generated we will find that it is greater than we expect. This is partly due to the fact that for both lighting and power purposes the load on the station is, as a rule, not uniform and the apparatus is not working under the best conditions for economy. In this country electrical energy is principally generated for electric lighting, for electric traction, and for supplying stationary motors, these stationary motors, as a rule, being supplied with current from lighting stations. If we take the load diagram of such stations in large towns, we will find that the average output is not greater than 30 to 40 per cent of the maximum output. We have, therefore, to supply a large amount of machinery corresponding to the maximum demand on the station, while for distribution a large amount of copper is required, that is only being used at its maximum capacity for a comparatively short period of the time. In stations supplying power for traction purposes we find a variation of load, but the variation is a different kind from that found in a lighting station. In the latter the load varies at different hours in the day, but for any particular instant it is practically constant. In the former the average load for different hours during which the station is operated will be practically constant, but there will be momentary variations, depending upon the size of the station and the type of traffic. Taking, for instance, a 2,000-horsepower station in Baltimore, I find that the average load is 48 per cent of the momentary maximum load. This difference in the kind of variation for the two types of stations necessitates employment

of different apparatus to obtain the maximum economy for each type. For lighting stations triple-expansion engines may be used, while for traction work, where the variation in the load is sudden and may occur after the steam is cut off from the high-pressure cylinder, it is not well in general to go beyond compound engines, and there is even a question as to whether simple engines are not more economical when condensing water can not be obtained. In any case, however, it is of the utmost importance, as regards economy of operation, that the load should be made as constant as possible.

Two distinct types of distribution are used for incandescent lighting in this country—the single-phase alternating current and the direct current 3-wire system. At the present time the former does not permit the supplying of power. As alternating distribution is at high potential, it does permit the location of the station where the conditions of maximum economy can be fulfilled. The 3-wire incandescent system, using low voltages, may be used for supplying motors, but the amount of copper necessitated by the low pressure has caused such stations to be located near the center of distribution, irrespective of the best conditions for the economical operation of the plant.

With the alternating system it seems impossible to provide even a moderately steady output, but with the continuous-current system the motor load during the day gives an average output greater in proportion to the maximum. Some years ago the question of the relative values of the alternating and direct-current systems was discussed, and for a while most of the stations installed were of the alternating type. At present the tendency seems rather in the direction of continuous-current stations, especially in towns where there is a large demand for current within a comparatively small area. There is a great advantage of direct currents, in that they allow the employment of storage batteries, which equalizes the load on the station. In almost all of the large lighting plants, both here and abroad, this plan has been adopted to a greater or less extent, and the results have been so favorable, that the battery equipments in many of our stations are being increased. The efficiency of batteries in lighting stations is comparatively high, while the depreciation has been greatly reduced, and is not now over 5 or 6 per cent per annum. In most systems, however, the full benefit of the storage batteries is not realized, as the batteries are placed in the station, and while the advantage of an approximately constant load is obtained, yet the further advantage offered in distribution is not secured. I will take this question up later.

In New York, Brooklyn, Boston, and Chicago a large proportion of the direct-current lighting stations are situated where it is expensive to handle the coal and ashes, and where the economy, due to condensation, is not obtained. It is also the custom to use several stations instead of a single large station, and this increases the cost of production both in operating expenses and fixed charges. The question arises

whether we have reached a point where it will be more economical to consolidate the stations in the best possible location for economical production of energy, and make use of the means of distribution which have been developed in the last few years to increase the radius at which energy can be supplied.

As far as traction stations are concerned, their efficiency and output would be increased by the use of batteries, both because the machinery would be steadily loaded, and because the most efficient type of apparatus could be used, as is the case in lighting stations. By the consolidation of railroad properties that has taken place in the last few years single corporations operate electric lines over extended areas. It is the custom to build a number of stations, each running a certain section of the line, the idea being that the decreased cost of copper and the decreased possibility of a shut down would more than compensate for the increased cost of operation and fixed charges. It is, again, important to consider the question whether we have not reached the point where a single station can be built in such a way that there is little or no possibility of any accident causing a suspension of the entire traffic of the system, and where improved methods of distribution will decrease the amount of copper, so that it will not exceed that required by the present method of using a number of generating stations.

If storage batteries are used, the two types of variable load belonging to lighting and power stations demand different types of battery. For lighting stations a considerable capacity is required, while the momentary variations of power stations do not require any great capacity, but demand as great a maximum output as battery manufacturers can obtain.

In water-power plants the conditions of economy are different. The location of the plant is of course definitely fixed, and the advisability of obtaining a uniform load by means of batteries depends upon the local conditions. If the water power is limited and is less than the demand, then it might be well to use batteries in order to increase the amount of salable power. Again, if the development is expensive, it might be cheaper to develop a smaller amount of power, pay for a smaller amount of machinery, and increase the output by the addition of batteries. These are questions that can only be decided by a knowledge of the local conditions.

We may conclude that while the practice in large lighting and traction systems is to multiply stations near centers of consumption, yet the economy of a single large station makes it important to consider whether it is not possible to concentrate our power at some point where the expenses will be a minimum, and distribute by some of the methods which have in the last few years proved successful and economical. It is important to make the station load steady, and this may be done for continuous-current lighting and traction plants by means of storage batteries.

ELECTRICAL DISTRIBUTION.

The distribution of electrical energy to consumers as distinguished from its transmission to long distances has been largely accomplished by the agency of continuous currents, although alternating currents have played an important part in incandescent lighting. As I have stated, a considerable proportion of current for lighting is distributed at constant potential on the three-wire system or at constant current on arc-light circuits, while power for traction circuits is distributed at approximately constant potential at an average of, say, 550 volts.

I shall first consider the condition of affairs in a traction system in a large city, where a number of suburban lines are operated. If direct distribution is attempted from a single station, it will be found that when the distance exceeds 5 or 6 miles a large amount of copper must be employed to prevent both excessive loss and excessive variation of potential on the lines. On suburban lines it is the latter consideration that usually determines the amount of copper used, and this is especially true on lines where there is a considerable excursion traffic. Even in the city itself, the supplying of sections at distances 3 or 4 miles from the station may require so much copper that it would be less expensive to operate separate stations. Several methods other than the direct method may be employed to remedy these difficulties. For outlying lines where the traffic is mainly of the excursion order, being variable both during the day and for different seasons, boosters may be advantageously used. It is perhaps best from reasons of economy to run the boosting dynamos from motors. These dynamos are series-wound, and are connected to feeders of such resistance that the fall of potential in the wire for a given current is compensated for by the rise in voltage of the booster. There is a decreased cost of copper incidental to this system due to the fact that the drop is not limited by considerations of regulation—the voltage at the end of the feeder being constant—while the transmission is at an increased potential. If the average station potential is 600 volts, and it is boosted 300 volts, then the copper for a given loss would be decreased in the ratio of 36 to 81. The booster system has the advantage of the direct system when the cost of the additional apparatus, together with the increased loss on the line, capitalized, is less than the increased cost of the copper necessary to produce the same result by the direct system. Whether the balance is in favor of one or the other depends on the distance and the variation of the load, and it is indifferent whether the variation in the latter occurs often or not.

If any transforming device is employed to feed a distant section of the line it must be remembered that the capacity of the device must be great enough to look out for the maximum demand on this section. Suppose, now, that we wish to feed some suburban line where the load has considerable momentary fluctuations, but where the traffic is moderately constant during the year; in this case the booster could be

used with a storage battery at the end of its feeder, the battery supplying the line. The advantages of this combination are greater than with the simple booster, and in many cases they will compensate for the interest and depreciation on the battery and the loss in it. If the arrangement is properly made the load on the booster and line wire will be practically constant, thus decreasing the capacity of the booster to that required for the average load, while less copper will be required for a given loss. As to the latter point, suppose a given amount of power is to be distributed in 24 hours, say 200 amperes at 600 volts, if the load is uniform, the loss will be proportional to $200^2 \times 24$ hours. If it is all distributed in 12 hours, the loss will be proportional to $400^2 \times 12$ hours, or twice as much. So, in the case of the steady load, the same power could be transmitted with the same loss with half the copper. It makes no difference whether the variation extends over 12 hours in 24 or occurs every other minute, the result will be the same. It is apparent, then, that it is of the utmost importance to keep the line steadily loaded, as well as the station, and this points to the location of the battery near the points of consumption and not in the station. By this system—a booster with storage batteries—it is possible, assuming the same loss, to transmit power to a distance of 10 miles with approximately the same amount of copper that would be required for a 5-mile transmission on the direct system. It would increase the economical radius of distribution twice and the area of distribution four times. A single station could economically supply lines within distances up to 10 or 12 miles. If it is desired to still further increase the radius of distribution, it is possible to do this by employing some of the alternating current methods that have come into use. I will discuss these methods later, but at this point I may remark that the use of stationary and rotary transformers permits the energy to be transmitted in the form of alternating currents, and to be changed again into continuous currents of any required voltage. These rotary transformers supplied by an alternating current, which is transmitted from the station at a high voltage, may be used to feed the line directly or they may be used to supply storage batteries which are connected to the line. In the latter case we have the advantage of decreased size of apparatus, of steady load on the station, and of a minimum cost of copper on the line; which system it would be best to employ would depend upon the distances and the character of the line and load.

Of the systems that I have proposed for city and suburban distribution from a single station, three have been successfully employed, namely, the booster system, the booster system with batteries, and rotary transformers operating directly on the line. When we consider the advantages of a single station and a steady load, it seems evident to me that many of the large traction systems would do well to concentrate their stations into one and to use the booster system with batteries for their outlying lines, and if necessary use rotary transformers for lines beyond the limit of ordinary suburban work. As to the pos-

sibility of the complete shut down of such a station, we have reached such a point in the construction of machinery, both electric and mechanical, that with a proper reserve, a careful system of duplex steam piping, and with fireproof construction of the station such a possibility may be disregarded; while the batteries would look out for any momentary interruption on the feeders.

CONTINUOUS CURRENT LOW VOLTAGE DISTRIBUTION.

Some of the most important stations supplying incandescent lamps are operated on the three-wire continuous current system. In the last few years a considerable advance has been made in the sale of power for motors from these stations, and this has increased the revenue and has given better average output. The tendency in this country has been in the direction of using storage batteries in such stations, and abroad practically every continuous current station uses batteries. As in the case of traction systems, it has been the custom in large cities to build a number of separate stations instead of building a single plant and distributing from it. The batteries have been placed in the stations themselves, and no attempt has been made to decrease the amount of copper used by employing a number of centers of distribution and giving the main feeders a steady load. The same considerations that apply to stations for traction work will also apply to stations used to supply lights, and the same methods of distribution may be used. It would unquestionably be more economical in many instances to use single stations to transmit power from these stations to centers of distribution, where batteries may be located and to distribute from these centers on a three-wire system. A case in point is the system used at Budapest, where the energy is distributed from the central station to rotary transformers at substations, these rotary transformers feeding batteries, current being distributed from these batteries on a three-wire system. The reports of the operation of this station show that it is both economical and successful, and it might well be copied by some of the companies in this country. The gross receipts of some of the large illuminating companies bear such a large proportion to the company's stock that a comparatively small saving in operation would mean a considerable increase in the dividends, and there is no doubt in my mind that by using one power station, with battery substations for distribution, the operating expenses can be considerably decreased.

ALTERNATING CURRENTS FOR LIGHTING.

Alternating currents have been employed for lighting in this country, and they have been especially valuable where a district is to be supplied in which the distances are considerable as compared with the number of customers. It has been almost the universal custom to supply small transformers for each consumer, and while the average size of transformers is greater now than it was a few years ago, yet they are comparatively small. No power has been supplied from such stations, and

although alternating arc lamps are used to a limited extent, yet the number is not increasing, and in some cases continuous-current arc lamps have been substituted for the alternating. Under these conditions the load on the station is even more variable than in the case of a continuous-current supply where motors may be employed, and the constant loss due to the large number of small transformers used places this system at a disadvantage as compared with the continuous-current system. The great advantage it possesses lies in the increased area of distribution rendered possible by the high voltages that are used, together with the possibility of locating the stations where power can be cheaply made. Abroad in the last few years most of the new stations that have been built use continuous currents, although some years ago the greater proportion of them were alternating-current stations. It is also the custom abroad to use substations with large transformers for distribution, thus doing away with a considerable part of the constant loss due to the small transformers used here. It is not possible, at the present time, without greatly complicating the system, to obtain a steady load on the station, and the only question that arises is the value of substations, and the possibility of using some form of alternating current other than the single-phase.

METHODS OF ELECTRICAL TRANSMISSION.

Coming to the question of transmission of electrical energy as distinguished from the supply to customers from distributing centers, there have been great advances made in the last few years, and these mainly through the introduction of multiphase alternating currents. Single-phase alternating currents permit the transmission of power to long distances and its distribution for lighting purposes. It is also possible to supply power from such circuits to large motors working under a steady load. It is not possible, however, to distribute power economically for ordinary uses. As most long-distance transmission schemes contemplate the substitution of electric motors for steam engines, and as their success will, in many cases, depend upon the possibility of such substitution, single-phase alternating currents are not at present able to comply with the conditions imposed by the desired service. The introduction of multiphase alternating systems, where two or more alternating currents are employed, the currents differing in phase, has completely changed the situation with respect to long-distance transmission. I shall consider briefly the possibilities of such systems and their value as compared with any direct-current system.

CONTINUOUS-CURRENT TRANSMISSION.

The first long-distance transmission plant was operated by the continuous-current system, and even now plants are being built in which continuous currents of high potential are used to transmit energy to distances up to 15 miles. As compared with transmission by means of alternating currents, we will find that the continuous-current system

possesses some advantages and some disadvantages. If we consider the relative cost of the copper in the line for a given amount of power transmitted and for a given maximum potential between the conductors, we will find that the relative amounts for the continuous-current and the different alternating-current systems will be as follows:

Continuous current	100
Single-phase alternating	200
Two-phase alternating	200
Three-phase alternating	150

We see, then, that the continuous-current has a marked advantage over the alternating-current system as far as the cost of copper is concerned. There are, however, certain practical disadvantages belonging to this system. The high voltages necessary for long-distance transmission makes it impossible to distribute the current at the receiving end without first reducing the voltage. With continuous current this can only be done by employing a rotary commutator of some kind. A plan which has been practically and successfully used has been to run a number of dynamos in series at the generating end of a line, while at the receiving end are a number of motors, also arranged in series, which are used to drive other generators to give the required type of current and the desired voltage. It has not been found possible to make either dynamos or motors of any great output, as there are practical difficulties in running dynamos of high potential where the current taken from them has a considerable value. Mons. Thury has installed a number of continuous-current transmission plants that have apparently given excellent results. At Biberist a transmission of 15 miles is employed. At Brescia 700 horsepower are transmitted over 12 miles at a maximum of 15,000 volts. Mons. Thury states that generators for 45 amperes can be constructed up to 3,000 volts, and he thinks that 4,000 could be successfully used. These machines, however, are small when compared with the 5,000-horsepower dynamos in use at Niagara, for instance; and where the transmission is a large one the great number of machines necessary would be a serious objection to this type of transmission. It will be seen that the greatest possibility of trouble in such a transmission lies at the ends of the line, in the generating and receiving apparatus. It is necessary, no matter what our voltage is, that both the dynamos and motors shall be directly subjected to it, and this with commutated machines will always be a source of danger. If we are to do any considerable amount of lighting from such a station, our energy for this purpose undergoes three transformations before it reaches the lamps, and the efficiency would not be so high as in a corresponding alternating-current system. It would hardly be possible to supply motors for ordinary work at the high voltages used for transmission, and the current for them would have to be transformed in the same manner as the current for the lamps. It must be recognized, however, that this system has been successfully used and has given excellent results in a few cases of transmission. Its great advantage lies in the

decreased amount of copper as compared with the alternating systems, and in the absence of induction effects, which are a drawback to alternating-current transmission.

TRANSMISSION BY ALTERNATING CURRENTS.

A large proportion of the transmission plants that have been installed in the last few years have been of the alternating current type. These have, as a rule, given satisfactory results, and the installations that are now being erected or planned are almost exclusively on an alternating current basis. The great advantage of this system lies in the fact that it is possible to change the voltage of the current without the use of rotating apparatus, and at once economically and safely. Low voltage dynamos may be used, the voltage may be increased in any desired ratio by stationary transformers, the energy may be transmitted at an increased voltage, and at the receiving end the voltage may again be reduced by transformers. If we compare this method with the continuous current system we will see that to obtain an alternating current of the required pressure at the receiving end of the line we would use the same number of transformations required by the continuous current system. We have the great advantage, however, that our changes in voltage have been obtained by the agency of stationary apparatus, which is much cheaper, is more efficient, and is safer than that required in the continuous current system. It is possible to increase the voltage by means of transformers to almost any value with perfect safety and with an efficiency as high as 98 per cent or 99 per cent. If, then, our alternating current, when it has been reduced at the receiving end, is as valuable for distribution as the current obtained by the direct current system, there will be no doubt that alternating transmission has great advantages over continuous currents.

I have spoken of the relative amounts of copper required by the single-phase, two-phase, and three-phase alternating currents. I do not think it necessary to explain minutely the difference between these systems, as they are well understood. In a single-phase system a single alternating current is used. In a two-phase system two alternating currents, whose phases differ by 90 degrees, are employed, while in the three-phase system there are three currents, differing in phases by 60 degrees. I shall consider the characteristics of these three systems, as there has been much discussion, especially as to the relative value of the last two of them, for transmission work. I shall not discuss the various modifications of the systems, but shall confine myself to general considerations. There is no single-phase motor in successful commercial operation that does not require to be started from rest by some outside means. This prevents a single-phase current from being used at the present time for power distribution; and as, in most transmission, the distribution of power is an important item, single-phase currents are not suitable for this purpose. In a two-phase system the currents are usually carried on separate pairs of wires, while in the three-phase system three wires are generally used, a common return being unneces-

sary, as the sum of the currents is zero, unless the circuits are unbalanced. In distributing on the three-phase system a fourth wire can be employed, as it gives an advantage in the amount of copper used.

In all these alternating systems the great difficulty lies in the fact that the inductance of the circuit causes the current to lag behind the electromotive force. This decreases the amount of energy transmitted by a given current at a given voltage; it causes a drop in the voltage of the line, and it increases the armature reaction of the dynamo for a given current. The total inductance of the circuit is made up of the inductance of the transformers, of the dynamos, of the receiving apparatus, and of the line. In the case of transmission to very long distances the line inductance is a large proportion of the total, while the inductance of the receiving apparatus depends upon whether lights or motors are to be supplied and upon the construction of the latter. When the different wires of the multiphase system are fed from windings on the same dynamo armature, then the drop in voltage due to any excess of load on one of these circuits can not be compensated for on the dynamo itself. If the amount of current and the lag of the current is the same for all of the circuits of the system, then it is easy, by a compounding winding of the dynamo, or by changing the current in the field winding, if there is no compounding, to keep the voltage constant at either the sending or receiving end. When the load on the different wires of the system is not the same, however, it is, as I have stated, impossible to keep all of the circuits at the proper voltage. Where a two-phase transmission with separate circuits is used, then if the separate circuits are wound on different armatures each can be regulated to give a constant voltage at the receiving end. This is the case, for instance, in the large dynamos built by the Westinghouse Company for use at the World's Fair in Chicago. The difficulty due to the uneven loading of the circuits is specially marked in the case of the three-phase system, and it is one of the principal objections that have been urged against the employment of this system for distribution. It should be pointed out, too, that it is not enough to balance the quantities of current for the three branches of the system, but the character of the current must also be considered. A noninductive load on one wire, with an inductive load of equal value on the others, would cause an unbalancing just as if the currents differed in amount. In most of the transmission plants that are being operated and that are proposed it is required to run both lamps and motors from the same circuits, and while a slight variation of potential on the motors would not cause any particular trouble, yet the successful operation of the lamps requires a practically constant voltage. I think, however, and the same grounds have been taken by others, that in any practical transmission of considerable size it is possible to so balance the loads that this difficulty will not exist to an extent to cause any serious trouble. When the distributing part of the lines is reached it is usually the custom, when a three-phase transmission is used, to employ four instead of three wires.

As for line inductance in the two-phase and three-phase systems, there is no question that the latter has an advantage in this respect. By suitable arrangement of circuits the line inductance can be brought to a minimum, and this is of the utmost importance in long-distance transmission. I will not take into account the supposed increased efficiency of three-phase motors and dynamos as against two-phase apparatus, as there is a question as to whether a superiority exists, but simply considering the decreased amount of copper required and the decreased inductance of the line, there is no question in my mind that, for transmission, the three-phase system is superior to the two phase. It is well known, of course, that the inductance of the circuit can be in some measure compensated for by the use of condensers or over-excited synchronous motors. The first of these remedies is, however, a very uncertain quantity commercially, while the second should be used as much as possible, that is, as many synchronous motors should be connected as is practicable. The best remedy, as things stand at present, lies in the careful construction of the line and the apparatus, so that the effects, although they exist, can be reduced to a minimum.

It has been shown by Mr. Scott and others that it is possible to transform a two-phase into a three-phase current, to transmit it and to transform it back again to a two-phase current. This will allow us, if we wish, to use two-phase dynamos for generating the current, to transmit with the advantage incidental to the use of three-phases, and at our reducing end to use two-phase circuits for transmission. This has some advantages as far as balancing the voltage on the circuits go, and it has been proposed in the case of several plants whose installation is being considered.

Looking broadly at the value of alternating transmission as against continuous current transmission, we have a gain in the simplicity and safety in the transmission, and at the distributing end the use of multiphase currents enables us to supply both lamps and power with an economy and success comparable to that of the continuous current system. If it is necessary to use continuous currents for certain types of distribution at the receiving end, they can be obtained by the use of rotary transformers, by which the alternating current is transformed into a continuous current. These machines have approximately the efficiency of corresponding continuous current dynamos, while the output for a given size is 50 per cent greater.

POSSIBLE VOLTAGES AND DISTANCES OF TRANSMISSION.

A number of calculations have been made as to the possibility of transmitting electrical energy to very long distances. If the question of cost of transmission alone is considered, then where water powers or culm heaps are within distances of 100 miles of some large center of consumption, it has been shown that it would be profitable to generate and transmit electrical energy. In these calculations, however, voltages are assumed that have never been employed for commercial plants, and whose availability is problematic, while sufficient stress is

not apparently laid on the question of the reliability of the power. If the industries of a large city depended upon a single transmission plant, it is evident that the question of reliability is of paramount importance. Where energy is supplied to manufacturers, to street-car systems, and for lighting, a breakdown that would involve the cutting off of current for a day would mean an enormous pecuniary loss to the community. As the distance of transmission increases, the possibility of accident is increased in greater ratio, because we have not only the higher voltages to control, but the length of the line that must be looked out for is also increased. The best guide lies in the practical experience which has been obtained in the present transmission plants and the consideration of the difficulties that have arisen and the remedies that have been employed. I have prepared a partial list of the principal transmission plants that are now in operation:

Name.	Type.	Distance, in miles.	Line voltage.	Horse power.	Remarks.
Ouray, Colo	Direct	4	800	1,200	Successful, increasing.
Geneva, Switzerland	do	20	6,600	400	Successful.
San Francisco, Cal	do	12	8,000	1,000	Successful, 9 years.
Brescia	do	12	15,000	700	
Pomona and San Bernardino.	Single phase alternating.	13½ to 28¾	1,000	800	Successful, increasing, 4 years.
Telluride, Colo	do	3	3,000	400	To be increased 3,200 H. P.
Bodie, Colo	do	12½	3,400	160	Successful.
Rome, Italy	do	18	6,000	2,000	Increasing to 9,000 H. P., 3 years.
Davos, Switzerland	do	2	3,660	600	Successful.
Schongeisung, Germany	do	4½	2,600	820	Do.
Springfield, Mass	2-phase alternating.	6½	3,600	820	Do.
Quebec, Canada	do	8	5,000	2,130	Do.
Anderson, S. C	do	8	5,500	200	Do.
Fitchburg, Mass	do	2¼	2,150	400	Do.
Winooski, Vt	3-phase	2½	2,500	150	Do.
Baltic, Conn	do	5	2,500	700	Do.
St. Hyacinthe, Canada	do	5	2,500	600	Successful, 2 years.
Concord, N. H	do	4	2,500	5,000	Do.
Fresno, Cal	do	35	11,000	1,400	Successful, to be increased.
Big Cottonwood to Salt Lake City, Utah.	do	14	10,000	1,400	Successful.
Lowell, Mass	do	6 to 15	5,500	480	Do.
Sacramento-Folsom, Cal	do	24	10,000	4,000	1 year.
Redlands, Cal	do	7½	2,500	700	3 years, extending lines in other towns.
Lauffen to Frankfort, Germany.	do	.100	30,000	300	(Experimental.)
Lauffen to Heilbronn	do	9	5,000	600	Successful.
Oerlikon Works, Zurich, Switzerland.	do	15½	13,000	450	Do.
Portland, Oreg	do	12	6,000	5,000	Do.
Silverton Mine, Colo	do	4	2,500	400	Successful, to be increased.

It will be seen that the longest transmission is at Fresno, Cal., the distance being about 35 miles. The highest alternating voltage used is 13,000 volts, at Zurich, Switzerland. The highest direct potential is 15,000 volts, at Brescia.

All of these plants are working successfully, and this fact will lead to still longer transmission and higher voltages. No limit of either distance or potential has yet been reached. If we consider the record of the present transmission plants, we can safely say that it would not be going outside of the safe limit of development to transmit at least 50 miles at a potential of 20,000 volts, provided the energy could be delivered at such a price as to be considerably lower than the cost of a corresponding amount of energy obtained from a steam plant. This, of course, is a matter of local condition entirely, and the commercial value of such a transmission will depend upon local conditions.

LONG-DISTANCE TRANSMISSION FOR RAILROAD WORK.

The possibility of long-distance electric-railroad lines is intimately connected with the possibility of long-distance transmission of power. We have seen that it is possible to transmit considerable distances from a single station. The current so distributed is not, however, such that it can be applied directly to railroad motors, but it must be transformed at points along the line, the distance apart of these points of distribution depending upon the system that is employed. At present continuous current motors are used, and considerations of safety would lead us to use line potentials not greater than 700 volts. By distributing rotary transformers at distances of 5 or 6 miles apart, we would be able to supply motors with current without any great investment in copper. The amount of copper required could be still further reduced by using rotary transformers with storage batteries thus keeping a constant load on the transmission line. It will be found, however, that on any long-distance railroad line, the load on any section of the line is exceedingly variable and the discharge rate of the batteries will have to be very high in order to prevent excessive cost for our reducing stations. It is doubtful whether we have reached a point in battery construction that this system of transmission would be economical. It is certain, however, that when the distances are comparatively short, say within 15 miles, and where the traffic is not evenly distributed, that rotary transformers, with or without batteries, can be economically employed for railroad work.

CONCLUSIONS.

My conclusions, subject always to the influence of local conditions, are as follows:

1. In both direct current lighting and traction systems, where the power is generated in or near the area of distribution, it is best to use one station situated at the most economical point for producing power.

2. In the case of the traction systems, when the economical area of direct distribution is passed, boosters should be employed directly or in connection with batteries, to a distance of 10 or 12 miles from a station, and beyond this rotary transformers, whether with or without batteries, should be used.

3. In the case of direct current lighting systems, the energy should be transmitted to storage batteries situated at centers of consumption either directly or by means of a rotary transformer and distributed from them.

4. Where batteries are used it is best to place them at the end of feeder wires to obtain the advantage of a constant load on the wire.

5. The best system for the long-distance transmission of energy for general purposes is the three-phase alternating system.

6. Commercial transmissions are in successful operation for distances of 35 miles, and for voltages as high as 15,000 volts.

Experience with these plants shows that the transmission to 50 miles with a pressure of 20,000 volts is practicable; beyond these limits the transmission would be more or less experimental.

THE UTILIZATION OF NIAGARA.[1]

By Thomas Commerford Martin.

The broad idea of the utilization of Niagara is by no means new, for even as early as 1725, while the thick woods of pine and oak were still haunted by the stealthy redskin, a miniature sawmill was set up amid the roaring waters. The first systematic effort to harness Niagara was not made until nearly one hundred and fifty years later, when the present hydraulic canal was dug and the mills were set up which disfigure the banks just below the stately falls. It was long obvious that even an enormous extension of this surface canal system would not answer for the proper utilization of the illimitable energy contained in a vast stream of such lofty fall as that of Niagara.

Niagara is the point at which are discharged, through two narrowing precipitous channels only 3,800 feet wide and 160 feet high, the contents of 6,000 cubic miles of water, with a reservoir area of 90,000 square miles, draining 300,000 square miles of territory. The ordinary overspill of this Atlantic set on edge has been determined to be equal to about 275,000 cubic feet per second, and the quantity passing is estimated as high as 100,000,000 tons of water per hour.

The drifting of a ship over the Horse Shoe Fall has proved it to have a thickness at the center of the crescent of over 16 feet. Between Lake Erie and Lake Ontario there is a total difference of level of 300 feet (fig. 1, Pl. VIII), and the amount of power represented by the water at the falls has been estimated on different bases from 6,750,000 horsepower up to not less than 16,800,000 horsepower, the latter being a rough calculation of Sir William Siemens, who, in 1877, was the first to suggest the use of electricity as the modern and feasible agent of converting into useful power some of this majestic but squandered energy.

It may be noted that the water passing out at Niagara is wonderfully pure and "soft," contrasting strongly, therefore, with the other body of water, turbid and gritty, that flows from the north out through the banks of the Mississippi. The annual recession of the American

[1]Read at extra evening meeting of Royal Institution of Great Britain June 19, 1896, by Thomas Commerford Martin, esq., of New York, *American Delegate to the Kelvin Celebration.* The Right Hon. Lord Kelvin, D. C. L., LL. D., F. R. S., vice-president, in the chair. Printed in Proceedings of the Institution, Vol. XV, pp. 269–279.

Fall, of $7\frac{1}{2}$ inches, and of the Horse Shoe, of 2.18 feet, would probably have been much greater had the water been less limpid.

The roar of the falls, which can be heard for many miles, has a deep note, four octaves lower than the scale of the ordinary piano. The fall of such an immense body of water causes a very perceptible tremor of the ground throughout the vicinity. The existence of the falls is also indicated by huge clouds of mist which, rising above the rainbows, tower sometimes a mile in air before breaking away.

It was Mr. Thomas Evershed, an American civil engineer, who unfolded the plan of diverting part of the stream at a considerable distance above the falls, so that no natural beauty would be interfered with, while an enormous amount of power would be obtained with a very slight reduction in the volume of the stream at the crest of the falls. Essentially scientific and correct as the plan now shows itself to be, it found prompt criticism and condemnation, but not less quickly did it rally the able and influential support of Messrs. W. B. Rankine, Francis Lynde Stetson, Edward A. Wickes, and Edward D. Adams, who organized the corporate interests that, with an expenditure of £1,000,000 in five years, have carried out the present work.

So many engineering problems arose early in the enterprise that after the survey of the property in 1890 an International Niagara Commission was established in London, with power to investigate the best existing methods of power development and transmission, and to select from among them, as well as to award prizes of an aggregate of £4,400. This body included men like Lord Kelvin, Mascart, Coleman Sellers, Turrettini, and Dr. Unwin, and its work was of the utmost value. Besides this the Niagara Company and the allied Cataract Construction Company enjoyed the direct aid of other experts, such as Prof. George Forbes, in a consultative capacity; while it was a necessary consequence that the manufacturers of the apparatus to be used threw upon their work the highest inventive and constructive talent at their command.

The time-honored plan in water-power utilization has been to string factories along a canal of considerable length, with but a short tail race. At Niagara the plan now brought under notice is that of a short canal with a very long tail race. The use of electricity for distributing the power allows the factories to be placed away from the canal, and in any location that may appear specially desirable or advantageous.

The perfected and concentrated Evershed scheme comprises a short surface canal 250 feet wide at its mouth, $1\frac{1}{4}$ miles above the falls, far beyond the outlying Three Sisters Islands, with an intake inclined obliquely to the Niagara River. This canal extends inwardly 1,700 feet, and has an average depth of some 12 feet, thus holding water adequate to the development of about 100,000 horsepower. The mouth of the canal is 600 feet from the shore line proper, and considerable work was necessary in its protection and excavation. The bed is now of clay,

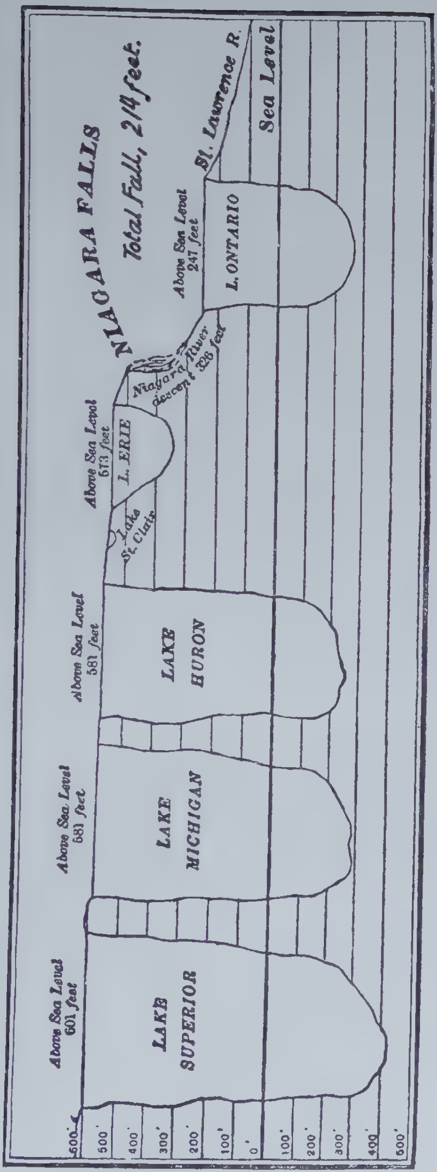


FIG. 1.—PROFILE SHOWING DIFFERENCE OF LEVEL OF THE GREAT LAKES.

and the side walls are of solid masonry 17 feet high, 8 feet at the base, and 3 feet at the top. The northeastern side of the canal is occupied by a power house, and is pierced by ten inlets guarded by sentinel gates, each being the separate entrance to a wheel pit in the power house, where the water is used and the power is secured. The water as quickly as used is carried off by a tunnel to the Niagara River again.

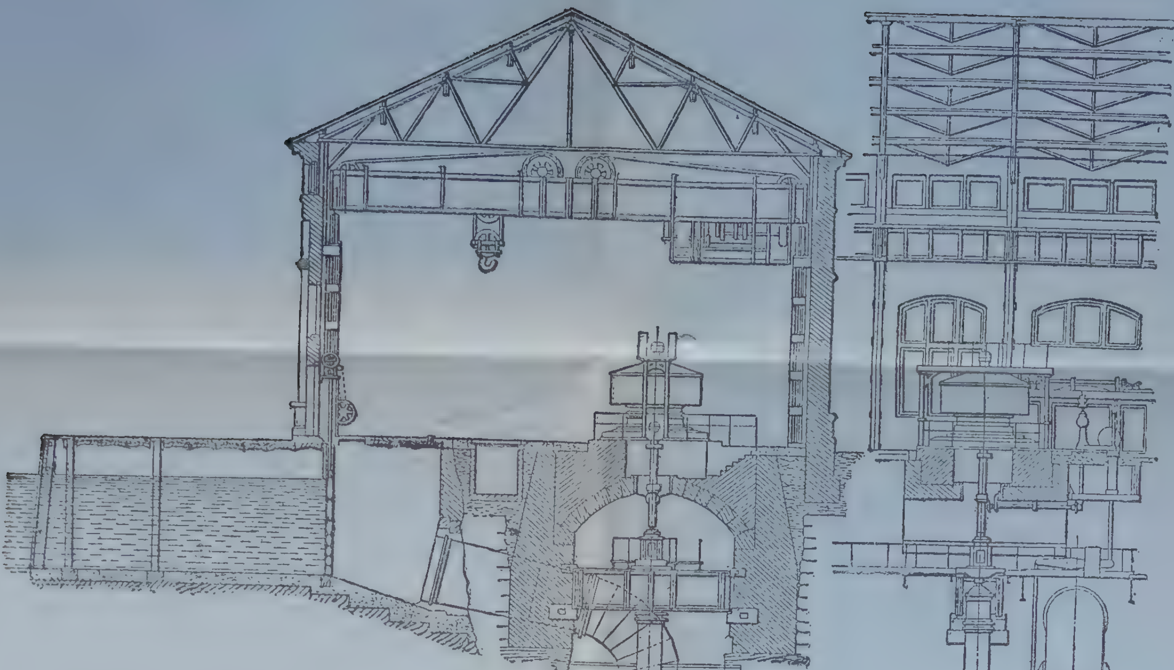
The massive canal power house is a handsome building, designed by Stanford White, and likely to stand until Niagara, spendthrift fashion, has consumed its way backward, through its own crumbling strata of shale and limestone, to the base of it. This building is outwardly of hard limestone, and inwardly of enamel brick and ordinary brick coated with white enamel paint. It is 200 feet in length at present, and has a 50-ton Sellers electric traveling crane for the placing of machinery and the handling of any parts that need repair. The wheel pit, over which the power house is situated, is a long, deep, cavernous slot at one side, under the floor, cut in the rock, parallel with the canal outside. Here the water gets a fall of about 140 feet before it smites the turbines. The arrangement of the dynamos generating the current up in the power house is such that each of them may be regarded as the screw at the end of a long shaft, just as we might see it if we stood an ocean steamer on its nose with its heel in the air. At the lower end of the dynamo shaft is the turbine (fig. 2, Pl. IX) in the wheel pit bottom, just as in the case of the steamer shaft we find attached to it the big triple or quadruple expansion marine steam engine. Perhaps we might compare the dynamo and the turbine to two reels, stuck one on each end of a long lead pencil, so that when the lower reel is turned the upper reel must turn also. You might also compare the dynamos to bells up in the old church steeple, and the turbines to the ringers in the porch, playing the chimes and triple bob majors by their work on the long ropes that hang down. The wheel pit which contains the turbines is 178 feet in depth, and connects by a lateral tunnel with the main tunnel running at right angles. This main tunnel is no less than 7,000 feet in length, with an average hydraulic slope of 6 feet in 1,000. It has a maximum height of 21 feet, and a width of 18 feet 10 inches, its net section being 386 square feet. The water rushes through it and out of its mouth of stone and iron at a velocity of 26½ feet per second, or nearly 20 miles an hour.

More than 1,000 men were employed continuously for more than three years in the construction of this tunnel. More than 300,000 tons of rock were removed, which have gone to form part of the new foreshore near the power house. More than 16,000,000 bricks were used for the lining, to say nothing of the cement, concrete, and cut stone. The labor was chiefly Italian. The brick that fences in the headlong torrent consists of four rings of the best hard-burned brick of special shape, making a solid wall 16 inches thick. In some places it is thicker than that. Into this tunnel discharges also by a special subtunnel the

used-up water from the water wheels of the Niagara Falls Paper Company. The turbines (fig. 3, Pl. IX) have to generate 5,000 horsepower each, at a distance of 140 feet underground, and to send it up to the surface. For this purpose the water is brought down to each by the supply penstock, made of steel tube, and $7\frac{1}{2}$ feet in diameter. This water impinges upon what is essentially a twin wheel, each receiving part of the stream as it rushes in at the center, the arrangement being such that each wheel is three stories high, part of the water in the upper tier serving as a cushion to sustain the weight of the entire revolving mechanism. These wheels, which have 32 buckets and 36 guides, discharge 430 cubic feet per second, and they make 250 revolutions per minute. At 75 per cent efficiency they give 5,000 horsepower. The shaft that runs up from each one to the dynamo is of peculiar and interesting construction. It is composed of steel three-fourths inch thick, rolled into tubes which are 38 inches in diameter. At intervals this tube passes through journal bearings or guides that steady it, at which the shaft is narrowed to 11 inches in diameter and solid, flaring out again each side of the journal bearings. The speed gates of the turbine wheels are plain circular rims, which throttle the discharge on the outside of the wheels, and which, with the cooperation of the governors, keep the speed constant within 2 per cent under ordinary conditions of running. These wheels are of the Swiss design of Faesch and Picard, and have been built by I. P. Morris & Co., of Philadelphia, for this work.

The dynamos thus directly connected to the turbines are of the Tesla two-phase type (fig. 4, Pl. X). Each of these dynamos produces two alternating currents, differing 90 degrees in phase from each other, each current being of 775 ampères and 2,250 volts, the two added together making, in round figures, very nearly 5,000 horsepower. This amount of energy in electrical current is delivered to the circuits for use when the dynamo is run by the turbine at the moderate speed of 250 revolutions per minute, or, say, 4 revolutions per second. Here, then, we have, broadly, a Tesla two-phase system embodying the novel suggestions and useful ideas of many able men, among whom should be specially mentioned Mr. L. B. Stillwell, the engineer of the Westinghouse Electric Company, upon whom the responsibility was thrown for its success.

Each generator, from the bottom of the bedplate to the floor of the bridge above it, is 11 feet 6 inches high. Each generator weighs 170,000 pounds, and the revolving part alone weighs 79,000 pounds. In most dynamos the armature is the revolving part, but in this case it is the field that revolves, while the armature stands still. It is noteworthy that if the armature inside the field were to revolve in the usual manner, instead of the field, its magnetic pull would be added to the centrifugal force in acting to disrupt the revolving mass; but as it is the magnetic attraction toward the armature now acts against the centrifugal force exerted on the field, and thus reduces the strains in the huge ring of spinning metal. The stationary armature inside the



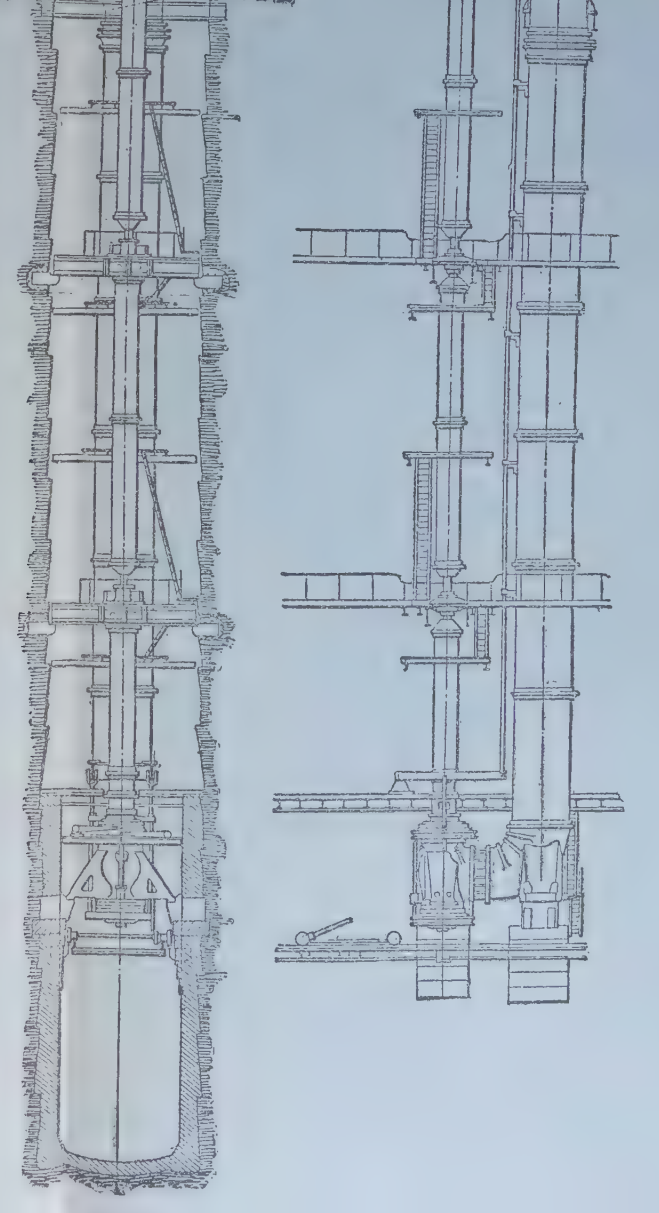


FIG. 2.—NEW 5000 H.P. TURBINE ARRANGEMENT, NIAGARA FALLS POWER CO. SIDE AND END ELEVATION SHOWING LATEST METHOD OF MOUNTING PENSTOCK AND TURBINE.

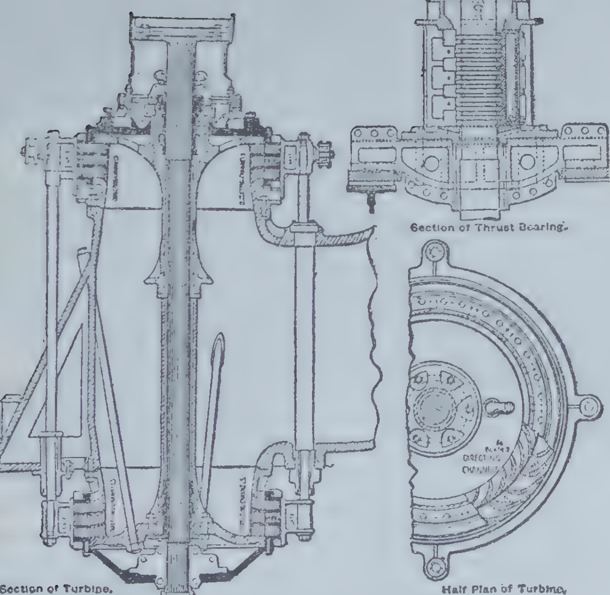


FIG. 3.—NIAGARA 5000 H.P. TURBINES, VERTICAL AND HORIZONTAL SECTIONS

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field is built up of thin sheets of mild steel. Along the edges of these sheets are 187 rectangular notches to receive the armature winding, in which the current is generated. This winding is in reality not a winding, as it consists of solid copper bars $1\frac{11}{32}$ by $\frac{7}{16}$ inch, and there are two of these bars in every square hole, packed in with mica as a precaution against heating. These copper conductors are bolted and soldered to V-shaped copper connectors, and are then grouped so as to form two separate independent circuits. A pair of stout insulated cables connect each circuit with the power-house switchboard.

The rotating field magnet outside the armature consists of a huge forged steel ring, made from a solid ingot of fluid compressed steel 54 inches in diameter, which was brought to a forging heat and then expanded upon a mandril, under a 14,000-ton hydraulic press, to the ring, 11 feet $7\frac{1}{2}$ inches in diameter. On the inside of this ring are bolted 12 inwardly projecting pole pieces of mild open-hearth steel, and the winding around each consists of rectangular copper bars incased in 2 brass boxes. Each pole piece, with its bobbin, weighs about $1\frac{1}{4}$ tons, and the speed of this mass of steel, copper, and brass is 9,300 feet, or $1\frac{3}{4}$ miles per minute, when the apparatus is running at its normal 250 revolutions. Not until the ring was speeded up to 800 revolutions, or 6 miles per minute, would it fly asunder under the impulse of centrifugal force. As a matter of fact, 400 revolutions is the highest speed that can be attained. This revolving field magnet is connected with the shaft that has to turn it, and is supported from above by a 6-armed cast-steel spider keyed to the shaft, this spider or driver forming a roof or penthouse over the whole machine. The shaft itself is held in 2 bearings inside the castings, around which the armature is built up, and at the bearings is nearly 13 inches in diameter. At the lower end is a flange fitting with the flange at the top of the turbine shaft, and at the upper end is a taper, over which the driver fits. The driver and shaft have a deep keyway, and into this a long and massive key fits, holding them solidly together. The driver is of mild cast steel, having a tensile strength of 74,700 pounds per square inch. The bushings of the bearings are of bronze, with zigzag grooves, in which oil under pressure is in constant circulation. Grooves are also cut in the hub of each spider to permit the circulation of water to cool the bearings, this water coming direct from the city mains at a pressure of 60 pounds to the square inch. The oil returns to a reservoir, and is used over and over again. Provision has been made against undue heating, and plenty of chance is given for air to circulate. This is necessary, as about 100 horsepower of current is going into heat, due to the lost magnetization of the iron and the resistance in the conductors themselves. Ventilators or gills in the drivers are so arranged as to draw up air from the base of the machine and eject it at considerable velocity, so that whatever heat is unavoidably engendered is rapidly dissipated.

In almost all electrical plants the switch board is a tall wall or slab

of marble or mahogany, not unlike a big front door with lots of knobs, knockers, and keyholes on it; but at the Niagara power house it takes the form of an imposing platform, or having in mind its controlling functions, we may compare it to the bridge of an ocean steamer, while the man in charge or handling the wheels answers to the navigating officer. The ingenious feature is employed of using compressed air to aid in opening and closing the switches. The air comes from a compressor located at the wheel pit and driven by a small water motor. It supplies air to a large cylindrical reservoir, from which pipes lead to the various switches, the pressure being 125 pounds to the square inch. Another interesting point is that the measuring instruments on the switch board do not measure the whole current, but simply a derived portion of determined relation to that of the generators. All told, less than a thirtieth of a horsepower gives all the indications required. To the switch board, current is taken from the dynamos by heavy insulated cable, and it is then taken off by huge copper bus bars which are carefully protected by layers of pure Para gum and vulcanized rubber, two layers of each being used; while outside of all is a special braided covering, treated chemically to render it noncombustible. The calculated losses from heating in a set of four bus bars carrying 25,000 horsepower, or the total output of the first five Niagara generators, is only 10 horsepower. About 1,200 feet of insulated cable have been supplied to carry the current from the dynamos to the switch board in the power house. It has not broken down until between 45,000 and 48,000 volts of alternating current were applied to it. There are 427 copper wires in that cable, consisting of 61 strands laid up in reverse layers, each strand consisting of 7 wires. Next to the strand of copper is a wall of rubber one-quarter inch thick, double coated. Over this is wrapped absolutely pure rubber, imported from England and known as cut sheet. Then come two wrappings of vulcanizable Para rubber, next there is a wrapping of cut sheet, and on top of that are two more rubber coats. This is then taped, covered with a substantial braid, and vulcanized. The object in using the cut sheet is to vulcanize it by contact, in order to make it absolutely water tight. This cable weighs just over 4 pounds to the foot, of which 3 pounds are copper and 1 pound insulation.

We have thus advanced far enough to get our current on to the bus bars, and the next step is to get it from them out of the power house. This final work is done by extending our bars, so to speak, and carrying them across the bridge over the canal, into what is known as the transformer house. It is here that the current received from the other side of the canal is to be raised in potential, so that it can be sent great distances over small wires without material loss. Meantime we may note that the Niagara Falls Power Company itself owns more than a square mile around the power house, upon which a large amount of power will be consumed in the near future by manufacturing establish-

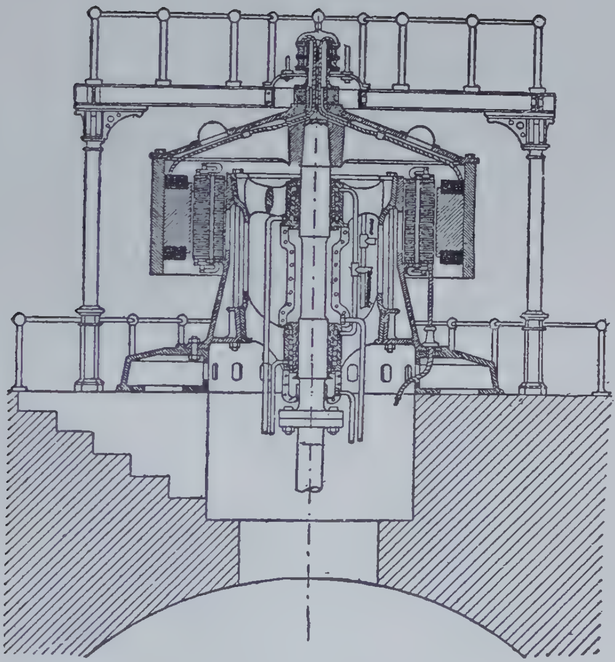

FIG. 4.—NIAGARA 5,000 HORSEPOWER TURBINES, TWO-PHASE ALTERNATOR.

ments of all kinds, and that it is already delivering power in large blocks electrically for a great variety of purposes. Special apparatus for this work has been built by the General Electric Company. The current for the production of aluminum is made "direct" by passing through static and rotary transformers, while the Acheson carborundum process uses the pure alternating current Besides this, the trolley road from Niagara to Buffalo is already taking part of its power from the Niagara power house by means of rotary transformers. For these and other local uses the company has constructed subways in which to carry the wire across its own territory. These subways are 5 feet 6 inches high and 3 feet 10 inches wide inside. They are built up with 12 inches of Portland cement and gravel, backed up with about 1 foot of masonry at the bottom and extending about 3 feet up each side.

The electric conductors are carried on insulated brackets or insulators arranged upon the pins along the walls. These brackets are 30 feet apart. At the bottom of the conduit manholes are holes for tapping off into side conduits, and along it all runs a track, upon which an inspector can propel himself on a private trolley car if necessary. Thus is distributed locally the electric power for which the consumer pays the very modest sum of £3 17*s*. 6*d*. per electrical horsepower per annum delivered on the wire, or about 2 guineas for a turbine horsepower, a rate which is not to be equaled anywhere, in view of the absolute certainty of the power, free from all annoyance, extra expense, or bother of any kind on the part of the consumer.

It is a curious fact that the proposal to transmit the energy of Niagara long distances over wire should have been regarded with so much doubt and scepticism, and that the courageous backers of the enterprise should have needed time to demonstrate that they were neither knaves nor fools, but simply brave, far-seeing men. We have to-day parallel instances to Niagara in the transmission of oil and natural gas. Oil is delivered in New York City over a line of pipe which is at least 400 miles long, and which has some thirty-five pumping stations en route, the capacity of the line being 30,000 barrels a day. All that oil has first to be gathered from individual wells in the oil region, and delivered to storage tanks with a capacity of 9,000,000 barrels of oil. Chicago, Philadelphia, and Baltimore are centers for similar systems of oil pipe running hundreds of miles over hill and dale. As for natural gas, that is to-day sent in similar manner over distances of 120 miles, Chicago being thus supplied from the Indiana gas fields; and the gas has its pressure raised and lowered several times on its way from the gas well to the consumer's tap, just as though it were current from Niagara.

We must not overlook some of the fantastic schemes proposed for transmitting the power of Niagara before electricity was adopted. One of them was to hitch the turbines to a big steel shaft running through New York State from east to west, so that where the shaft passed a town or factory all you had to do was to hitch on a belt or some gear

wheels and thus take off all the power wanted. Not much less expensive was the plan to have a big tube from New York to Chicago, with Niagara Falls at the center, and with the Niagara turbines hitched to a monster air compressor, which should compress air under 250 pounds pressure to the square inch in the tube.

So far as actual electrical long-distance transmission from Niagara is concerned, it can only be said to be in the embryonic stage, for the sole reason that for nearly a year past the power company has been unable to get into Buffalo, and that not until last year was it able to arrive at acceptable conditions, satisfactory alike to itself and to the city. Work is now being pushed, and by June, 1897, power from the falls will, by contract with the city, be in regular delivery to the local consumption circuits at Buffalo, 22 miles away. But the question arises, and has been fiercely discussed, whether it will pay to send the current beyond Buffalo. Recent official investigations have shown that steam power in large bulk, under the most favorable conditions, costs to-day in Buffalo £10 per year per horsepower and upward. Evidently Niagara power, starting at £2 on the turbine shaft or say less than £4 on the line, has a good margin for effective competition with steam in Buffalo.

As to the far-away places, the well-known engineers Prof. E. J. Houston and Mr. A. E. Kennelly have made a most careful estimate of the distance to which the energy of Niagara could be economically transmitted by electricity. Taking established conditions and prices that are asked to-day for apparatus, they have shown, to their own satisfaction at least, that even in Albany or anywhere else in the same radius 330 miles from the falls, the converted energy of the great cataract could be delivered cheaper than good steam engines on the spot could make steam power with coal at the normal price there of 12s. per ton.

What this enterprise at Niagara aims to do is not to monopolize the power but to distribute it, and it makes Niagara, more than it ever was before, common property. After all is said and done, very few people ever see the falls, and then only for a chance holiday once in a lifetime; but now the useful energy of the cataract is made cheaply and immediately available every day in the year to hundreds and thousands, even millions of people, in an endless variety of ways.

We must not omit from our survey the Erie Canal, in the revival and greater utilization of which as an important highway of commerce Niagara power is expected to play no mean part. In competition with the steam railway, canals have suffered greatly the last fifty years. In the United States, out of 4,468 miles of canal built at a cost of £40,000,000, about one-half has been abandoned and not much of the rest pays expenses. Yet canals have enormous carrying capacity, and a single boat will hold as much as twenty freight cars. The New York State authorities have agreed to conditions by which Niagara energy can be used to propel the canal boats at the rate of £4 per horsepower

per year. Where steamboat haulage for 242 tons of freight now costs about 6½d. a boat mile, it is estimated that electric haulage will cost not to exceed 5¼d., while with the energy from Niagara at only £4 per horsepower per year it will cost much less. Some two years ago the first attempt was made in the United States on the Erie Canal with the canal boat *F. W. Hawley*, when the trolley system was used with the motor on the boat as it is on an electric car, driving the propeller as if it were the car wheels. Another plan is that of hauling the boat from the towpath, and that is what is now being done with the electric system of Mr. Richard Lamb on the Erie Canal at Tonawanda, near Niagara. Imagine an elevator shaft working lengthwise instead of vertically. There is placed on poles a heavy fixed cable on which the motor truck rests, and a lighter traction cable is also strung that is taken up and paid out by a sheave as the motor propels itself along and pulls the canal boat to which it is attached. If the boats come from opposite directions they simply exchange motors, just as they might mules or locomotives, and go on without delay.

On its property at Niagara the power company has already begun the development of the new village called Echota, a pretty Indian name which signifies "place of refuge." I believe it is Mr. W. D. Howells, our American novelist, who in kindred spirit speaks of the "repose" of Niagara. It was laid out by Mr. John Bogart, formerly State engineer, and is intended to embody all that is best in sanitation, lighting, and urban comfort. It does not need the eye of faith to see here the beginning of one of the busiest, cleanest, prettiest, and healthiest localities in the Union. The workingman whose factory is not poisoned by smoke and dust, whose home was designed by distinguished architects, whose streets and parks were laid out by celebrated engineers, and whose leisure is spent within sight and sound of lovely Niagara, has little cause for grumbling at his lot.

The American company has also preempted the great utilization of the Canadian share of Niagara's energy. The plan for this work proposes the erection of two power houses of a total ultimate capacity of 125,000 horsepower. Each power house is fed by its own canal and is therefore an independent unit. Owing to the better lay of the land, the tunnels carrying off the water discharged from the turbines on the Canadian side will have lengths respectively of only 300 and 800 feet, thus avoiding the extreme length and cost unavoidable on the American side. With both the Canadian and American plants fully developed, no less than 350,000 horsepower will be available. The stationary engines now in use in New York State represent only 500,000 horsepower. Yet the 350,000 horsepower are but one-twentieth of the 7,000,000 horsepower which Professor Unwin has estimated the falls to represent theoretically. If the 350,000 horsepower were estimated at £4 per year per horsepower, and should replace the same amount of steam power at £10, the annual saving for power in New York State alone would be more than £2,000,000 per year.

Let me, by way of conclusion, emphasize the truth that this splendid engineering work leaves all the genuine beauty of Niagara untouched. It may even help to conserve the scene as it exists to-day, for the terrific weight and rush of waters over the Horseshoe Fall is eating it away and breaking its cliff into a series of receding slopes and rapids; so that even a slight diminution of the whelming mass of wave will to that extent lessen disruption and decay. Be that so or not so, those of us who are lovers of engineering can now at Niagara gratify that taste in the unpretentious place where some of this vast energy is reclaimed for human use, and then as ever join with those who, not more than ourselves, love natural beauty, and find with them renewed pleasure and delight in the majestic, organ-toned, and eternal cataract.

EARTH-CRUST MOVEMENTS AND THEIR CAUSES.[1]

By Joseph Le Conte.

INTRODUCTION—SOURCES OF ENERGY.

Nearly all the processes of nature visible to us—well-nigh the whole drama of nature enacted here on the surface of the earth—derive their forces from the sun. Currents of air and water in their eternally recurring cycles are a circulation driven by the sun. Plants derive their forces directly, and those of animals indirectly through plants, from it. All our machinery, whether wind driven, or water driven, or steam driven, or electricity driven, and even all the phenomena of intellectual, moral, and social activity have still this same source. There is one, and but one, exception to this almost universal law, namely, that class of phenomena which geologists group under the general head of igneous agencies, comprising volcanoes, earthquakes, and more gradual movements of the earth's crust.

Thus, then, all geological agencies are primarily divided into two groups. In the one group came atmospheric, aqueous, and organic agencies, together with all other terrestrial phenomena which constitute the material of science; in the other group, igneous agencies and their phenomena alone. The forces in the one group are exterior; in the other, interior; in the one, sun derived; in the other, earth derived. The one forms, the other sculptures, the earth's features; the one roughhews, the other shapes. The general effect of the one is to increase the inequalities of the earth's surface, the other to decrease and finally to destroy them. The configuration of the earth's surface, the distribution of land and water—in a word, all that constitutes physical geography at any geological time—is determined by the state of balance between these two eternally antagonistic forces.

PHENOMENA TO BE STUDIED.

Now the phenomena of the first group, lying, as they do, on the surface and subject to direct observation, are comparatively well under-

[1] Annual address by the president, Joseph Le Conte, read before the Geological Society of America, December 29, 1896. Printed in Science, Vol. V, No. 113, pp. 321–330.

stood as to their laws and their causes. While the causes of the phenomena of the second group, hidden forever from direct observation in the inaccessible depths of the earth's interior, are still very obscure; and yet partly on account of this very obscurity, but mainly on account of their fundamental importance, it is just these which are the most fascinating to the geologist. The former group, constituting, as it does, the terrestrial drama enacted by the sun, its interest is shared by geology equally with other departments of science, such as physics, chemistry, and biology. The phenomena of the second group are more distinctively the field of geology.

If we compare the earth with an organism then these interior forces constitute its life force, while the other group may be likened to the physical environments against which it eternally struggles, and the outcome of this struggle determines the course of the evolution of the whole. Now in biological science nearly the whole advance has heretofore been by study of the external and more easily understood phenomena, thus clearing the ground and gathering material for attack on the interior fortress, and the next great advance must be through better knowledge of the vital forces themselves. The same is true of geology. Nearly all the progress has heretofore been by the study of the exterior phenomena, such as erosion, transportation, sedimentation, stratification, distribution of organic forms in space, and their succession in time, etc. Many of the laws of these phenomena have already been outlined, and progress to-day is mainly in filling in and completing this outline; but the next great step must be through a better knowledge of the interior forces. This is just what geological science is waiting for to-day. Now the first step in this direction is a clear statement of the problems to be solved. The object of this address is to contribute something, however small, to such clear statement.

EFFECTS OF INTERIOR FORCES.

As the interior of the earth is inaccessible to direct observation, we can reason concerning interior forces only by observation of their effects on the surface. Now these effects, as usually treated, are of three main kinds: (1) Volcanoes, including all eruptions of material from the interior; (2) earthquakes, including all sensible movements, great and small; (3) gradual small movements affecting large areas, imperceptible to the senses, but accumulating through indefinite time.

It is certain that of these three the last is by far the most fundamental and important, being, indeed, the cause of the other two. Volcanoes and earthquakes, although so striking and conspicuous, are probably but occasional accidents in the slow march of these grander movements. It is only of these last, therefore, that we shall now speak.

KINDS AND GRADES OF EARTH-CRUST MOVEMENTS.

The movements of the earth's crust determined by interior forces are of four orders of greatness: (1) Those greatest, most extensive, and

probably primitive movements by which oceanic basins and continental masses were first differentiated and afterwards developed to their present condition; (2) those movements by lateral thrust by which mountain ranges were formed and continued to grow until balanced by exterior erosive forces; (3) certain movements, often over large areas, but not continuous in one direction, and therefore not indefinitely cumulative like the two preceding, but oscillatory, first in one direction, then in another, now upward and then downward; (4) movements by gravitative readjustment, determined by transfer of load from one place to another. Perhaps this last does not belong strictly to pure interior or earth-derived forces, since the transfer of load is probably always by exterior or sun-derived forces. Nevertheless they are so important as modifying the effects of other movements, and have so important a bearing on the interior condition of the earth that they can not be omitted in this connection.

Now of these four kinds and grades of movement the first two are primary and continuous in the same direction, and therefore cumulative, until balanced by leveling agencies. The other two, on the contrary, are not necessarily continuous in the same direction, but oscillatory. They are, moreover, secondary and are imposed on the other two or primary movements as modifying, obscuring, and often even completely masking their effects. This important point will be brought out as we proceed. We will take up these movements successively in the order indicated above.

1. OCEAN BASIN-MAKING MOVEMENTS.

I have already given my views on this most fundamental question very briefly in my "Elements of Geology," a little more fully in my first paper, "Origin of Earth Features,"[1] and in my memoir of Dana.[2] I give it still more fully now.

We may assume that the earth was at one time an incandescent, fused spheroid of much greater dimensions than now, and that it gradually cooled, solidified, and contracted to its present form, condition and size. Now if at the time of its solidification it had been perfectly homogeneous in composition, in density, and in conductivity in every part, then the cooling and contraction would have been equal on every radius, and it would have retained its perfect, evenly spheroidal form; but such absolute homogeneity in all parts of so large a body would be in the last degree improbable. If, then, over some large areas the matter of the earth were denser and more conductive than over other large areas, the former areas, by reason of their greater density alone, would sink below the mean level and form hollows; for even in a solid—much more in a semi-liquid, as the earth was at that time—there must have been static equilibrium (*isostasy*) between such large areas. This would be the beginning of oceanic basins; but the inequalities from this cause

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[1] Am. Jour. Sci., 1872.

[2] Bull. Geol. Soc. Am., Vol. 7, 1895, pages 461–474.

alone would probably be very small but for the concurrence of another and much greater cause, viz, the greater conductivity of the same areas. Conductivity is not, indeed, strictly proportional to destiny; but in a general way it is so. It is certain, therefore, that the denser areas would be also the more conductive, and therefore the more rapidly cooling and contracting areas. This would again increase, and in this case progressively increase, the depression of these areas. The two causes—destiny and conductivity, isostasy and contraction—would concur, but the latter would be far the greater, because indefinitely cumulative. The originally evenly spheroidal lithosphere would thus be deformed or distorted, and the distortion, fixed by solidification, would be continually increased until now. When the earth cooled sufficiently to precipitate atmospheric vapor the watery envelope thus formed would accumulate in the basins of the lithosphere and form the oceans. It is possible, and even probable, that the depressions were at first so shallow that the primeval ocean may have been universal, but the process of greater downward contraction continuing, the ocean basins would become deeper and the less contracted portions of the lithosphere would appear as land. The process still continuing, the land would grow higher and more extensive and the ocean basins deeper and less extended throughout all geological time. On the whole, in spite of many oscillations, with increase and decrease of land, to be spoken of later, and in spite, too, of exterior agencies by erosion and sedimentation tending constantly to counteract these effects, such has been, I believe, the fact throughout all geological history.

It is evident, also, that on this view, since the same causes which originally formed the ocean basins have continued to operate in the same places, the positions of these greatest inequalities of the lithosphere have not substantially changed. This is the doctrine of the permanency of oceanic basins and continental masses, first announced by Dana. Some modification of this idea will come up under another head.

The objection which may be—which has been—raised against this view is that such heterogeneity as is here supposed, in a fused mass and therefore in a mass solidified from a state of fusion, is highly improbable, not to say impossible. This objection, I believe, will disappear when we remember the very small differences in conductivity, and therefore in contraction, that we are here dealing with; small, I mean, in comparison with the size of the earth. This is evident when we consider the inequalities of the earth's surface. The mean depth of the ocean is about $2\frac{1}{2}$ miles; the mean height of the land about $\frac{1}{3}$ of a mile. The mean inequality of the lithosphere, therefore, is less than 3 miles. This is $\frac{1}{1350}$ of the radius of the earth—less than $\frac{1}{100}$ of an inch (an almost imperceptible quantity) in a globe 2 feet in diameter. I believe that a perfect spheroidal ball of plastic clay allowed to dry, or even a spheroidal ball of red-hot copper allowed to cool, would show more deformation by contraction than the lithospere of the earth in its

present condition. It is true the inequalities are more accentuated in some places, especially on the margins of the continental areas; but this is due to another cause, mountain making, to be taken up later.

Another objection will doubtless occur to the thoughtful geologist. It would seem at first sight on this view that ocean areas cooling most rapidly ought to be the first to form a solid crust, and the crust (if there be any interior liquid still remaining) ought to be thickest, and therefore least subject to volcanic activity, there; but, on the contrary, we find that it is just in these areas that volcanoes are most abundant and active. It is for this reason that Dana believed that land areas were the first and ocean areas the last to crust over. This is probably true; but a little reflection will show that these two facts—namely, the earlier crusting of the land areas and the more rapid cooling and contraction of the ocean areas—are not inconsistent with one another; for the more conductive and rapidly-cooling areas would really be the last to crust, because surface solidification would be delayed by the easy transference of heat from below, while the less conductive land areas would certainly be the first to crust, because the nonconductivity of these areas would prevent the access of heat from below. Observation of lavas proves this. The most vesicular and nonconductive lavas are the soonest to crust, but for that very reason the slowest to cool to great depths.

No doubt many other objections may be raised, especially if we attempt to carry out the idea into detail; for the physical principles involved, and especially the conditions under which they acted, are far too complex and imperfectly understood to admit of such detail. It is safest, therefore, to confine ourselves to the most general statement.

It may be well to stop a moment to compare with the above view that of Dana, as interpreted and clearly presented by Gilbert in 1893.[1] (1) According to this view the earth is supposed to have at first solidified at the center. This, on the whole, seems most probable. (2) The investing liquid, say from 50 to 100 miles thick, might well be supposed to arrange itself in layers of increasing density from the surface to the solid nucleus. Now suppose for any cause, less conductivity or other, certain areas crusted on the surface. These crusts would, of course, consist of the lighter superficial portions; but since rocks contract in the act of solidification,[2] these solidified crusts would sink to the nucleus and be replaced by similar lighter material flowing in from the surrounding surface, which in turn would solidify and sink. Thus would be built up from the nucleus below a solid mass consisting only of the superficial, lighter material, to form the land, while the denser and less rapidly crusting material would form the ocean areas. As in my view, therefore, the oceanic areas are the denser and the land areas the lighter material.

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[1] Bull. Geol. Soc. Am., vol. 4, 1893, page 179.

[2] King and Barus. Am. Jour. Sci., vol. 45, 1893, page 1.

It is evident that, according to either view, but especially according to mine, the material of the ocean basin areas down to the center of the earth must be as much denser than the material of the land areas down to the center as the subocean radii are shorter than the subcontinental radii, and therefore that the two areas must be in perfect static equilibrium with one another. Thus in the formation of continents the claims of isostasy are completely satisfied. I say completely, because this is not a partial equilibrium resisted by rigidity but enforced by pressure; it is original and without stress.

2. MOUNTAIN-MAKING MOVEMENTS.

I have so recently discussed this subject[1] that I shall have little more to say now. Mountain ranges are of two types, namely, the anticlinal or typical and the monoclinal or exceptional. The one are mountains of folded structure, determined by lateral thrust, the other of simpler structure and determined by unequal settling of great crust blocks. It is only of the former that I shall speak now. The other or monoclinal type will come up under another head.

It will not be questioned that mountain ranges of the first type are formed by lateral thrust, however much we may differ as to the cause of such thrust; nor will it be questioned that they are permanent features determined by continuous movement, however much they may be modified by other kinds of movement or reduced or even destroyed by subsequent erosion. I have placed them, therefore, among the effects of primary movements—that is, movements determined by causes affecting the whole earth. I have done so because until some more rational view shall be proposed I shall continue to hold that they are the effects of interior contraction concentrated upon certain lines of weakness of the crust and, therefore, of yielding to the lateral thrust thus generated. The reason for, as well as the objections to, this view I have already, on a previous occasion, fully discussed. I wish now only to supplement what I have before said by some further criticisms of the most recent and, some think, the most potent objections to this contractional theory, namely, that derived from the supposed position of the "level of no strain."

It is admitted that the whole force of this objection is based on the extreme superficiality of this level, and that this, in its turn, depends on the initial temperature of the incandescent earth and the time elapsed since it began to cool. Both these are admitted to be very uncertain. I have already discussed these in my previous paper and shall not repeat here; but, as recently shown by Davison,[2] there are still other elements, entirely left out of account in previous calculations, which must greatly affect the result, and these new elements all concur

[1] President's address, Am. Asso. Adv. Sci., Madison meeting, 1893.
[2] Am. Jour. Sci., Vol. 47, 1894, page 480; Phil. Mag., Vol. 41, 1896, page 133.

to place the level of no strain much deeper than previous calculations would make it.

These neglected elements are the following: (1) The earth increases in temperature as we go down. Now, the coefficient of contraction increases with temperature. This would increase the depth of the level of no strain, and also, of course, the amount of interior contraction, and, therefore, the lateral thrust. (2) The conductivity increases with the temperature. This also would increase the rate of cooling and, therefore, of interior contraction. (3) The interior of the earth is more conductive not only on account of its greater temperature, but also on account of its greater density; and this would be true whether the greater density be due to increased pressure or to difference of material, as, for example, to greater abundance of unoxidized metals. (4) The materials of the interior, aside from greater temperature and density, have a higher coefficient of contraction. (5) The usual calculations go on the assumption that the initial temperature was uniform for all depths. It probably increased with the depth then as now. This would again increase in an important degree both the depth of the level of no strain and the amount of lateral thrust.

The final result reached by Davison is, that while according to the usual calculations the level of no strain may be only a little over two miles (2.17) below the surface, yet, taking into account only the first element mentioned above, the depth of that level would be increased to nearly eight miles (7.79), and taking into account all the elements it would come out many times greater still. The general conclusion arrived at is that the objections to the contractional theory, based on the depth of the level of no strain, must be regarded as invalid.

3. OSCILLATORY MOVEMENTS.

The movements thus far considered are continuously progressive in one direction as long as they last. The resulting features are therefore permanent, except in so far as they may be modified by other movements or by degrading influences: but nothing is more certain than that besides these more steady movements there have been others of a more oscillatory character—that is, upward and downward—in the same place, affecting now smaller, now larger areas, and often many times repeated. These are the most common of all crust movements, and are shown everywhere and in all periods of the earth's history by unconformities of the stratified series. Every line of unconformity marks an old eroded land surface, and every conformable series of strata a sea bottom receiving sediments. We give but two striking examples of such oscillations.

The Colorado plateau was a sea bottom, continuously, or nearly so, from the beginning of the Carboniferous to the end of the Cretaceous, and during that time received about 12,000 or 15,000 feet in thickness of sediments. During the whole of this time the area of the earth's

crust was slowly sinking and thus continually renewing the conditions of sedimentation. Why did it subside? At the end of the Cretaceous the same area began to rise. What change of conditions caused it now to rise? It has continued to rise until the present time, and is still rising. The whole amount of rise can not be less than 20,000 feet; for if all the strata which have been removed by erosion were again restored, the highest portion of the arch which was sea bottom at the end of the Cretaceous would now be 20,000 feet high. This, however, is only the last oscillation of this area, for beneath the Carboniferous there are several unconformities showing several oscillations of the same kind in earlier periods. During the Devonian the area was land, for the Carboniferous rests uncomformably on the Silurian. During the Silurian it was sea bottom, receiving sediments of that time. Beneath the Silurian there are two other uncomformities showing similar oscillations. These earlier oscillations were probably as great as the one now going on, but we can not measure them as we can the last.

Another striking example, still more recent and widespread, is the enormous oscillations of the Glacial period. It can not be doubted that over very wide areas—several millions of square miles—there were at that time upward and downward movements of several thousand feet, and therefore producing enormous changes in physical geography and climate. What was the cause of these movements? They were doubtless modified, as will be shown later, by other movements superimposed on them; but the causes of the latter must not be confounded with that of the former.

We have given only two striking examples, but they are really the commonest of all crust movements. They are everywhere marked by unconformities of the strata; they are everywhere going on at the present time. In some places the sea is advancing on a subsiding land; in others a rising land is advancing on the sea. These movements are more conspicuous along coast lines, because the sea is a datum level by which to measure them, but they affect equally the interior of continents, as shown by the behavior of the rivers, which seek their base level by erosion in a rising and by sedimentation in a sinking country.

Many theories have been advanced to explain these movements, especially of certain very local shore-line movements. In volcanic regions they have been attributed to rise or recession of the volcanic heat and consequent columnar expansion or contraction of the crust. On nonvolcanic sedimentary shore lines elevation has been attributed by some to the rise of the interior heat of the earth and consequent expansion of the crust produced by the blanketing effect of sedimentary deposit; while others, with more reason, think that regions of heavy sedimentation sink under the increasing load of accumulating sediments; but it is evident that, while such theories may explain some local examples in volcanic regions and along some shore lines, they can not explain subsidences in the interior of continents, much less the

wider and more extensive movements spoken of above. We must look for some more general cause. What is it?

It must be confessed that the cause of these oscillatory movements is the most inexplicable problem in geology. Not the slightest glimmer of light has yet been shed on it. I bring forward the problem here, not to solve it, for I confess my inability, but to differentiate it from other problems, and especially to draw attention to these movements as modifying the effects of movements of the first kind, and often so greatly modifying them as to obscure the principle of the permanency of oceanic basins and continental areas, and even to cause many to deny its truth. Nearly all the changes in physical geography in geological times, with their consequent changes in climate and in the character and distribution of organic forms—in fact, nearly all the details of the history of the earth—have been determined by these oscillatory movements; but amid all these oscillatory changes, sometimes of enormous amount and extent, it is believed that the places of the deep oceanic basins and of the continental masses, being determined by other and more primary causes, have remained substantially the same.

4. MOVEMENTS BY GRAVITATIVE READJUSTMENTS—ISOSTASY.

This very important principle which, though partially recognized by Herschell, was first clearly enunciated by Major Dutton under the name isostasy.[1] The principle may be briefly stated thus: In so large a mass as the earth, whether liquid within or solid throughout it matters not, excess or deficit of weight over large areas can not exist permanently. The earth must gradually yield fluidally or plastically until static equilibrium is established or nearly so. Thus continuous transfer of material from one place to another by erosion and sedimentation must be attended with sinking of the crust in the loaded and rising of the crust in the unloaded area. In this way we may account for the sinking of the crust at the mouths of great rivers and the correlative rising of interior plateaus and nearly all great mountain regions observable at the present time. The same seems to have been true in all geological times, for it is obviously impossible that 40,000 feet of sediments could have accumulated in the Appalachian region in preparation for the Appalachian's birth unless there were continuous *pari passu* subsidence ever renewing the conditions of sedimentation.

Now, there can be no doubt as to the value of this principle, but there is much doubt as to the extent of its application. The operation of exterior causes, such as transfer of load by erosion and sedimentation, are so comparatively simple and their effects so easily understood that we are tempted to push them beyond their legitimate domain, which in this case is to supplement and modify the more fundamental movements derived from interior causes. We are thus tempted to generalize too hastily and to conclude that all subsidence is due to weight-

[1] Phil. Society of Washington, 1892.

ing and all elevation to removal of weight. Probably this is a true cause, but not the main cause of such movements. Doubtless the proposition is true, but its converse is even much more so. It is certain that thick sediments may cause subsidence, but it is much more certain that subsidence, however determined, will cause continuous sedimentation by ever renewing the conditions of sedimentation. It is true that removal of weight by erosion will cause elevation, but it is more certain that elevation is the cause of removal of matter by erosion.

Take again the Plateau region as an example. We have seen that during the whole Carboniferous, Permian, Triassic, Jurassic, and Cretaceous times this region was subsiding, until at the end of the Cretaceous the earth's crust here had bent downward 12,000 or 15,000 feet. Shall we say it went down under the increasing load of sediments? Why, then, did it, from a previous land condition, ever commence to subside? And why, when the load was greatest, namely, at the end of the Cretaceous, did it begin to rise? Again, from that time to this it has risen 20,000 feet. Of this, about 12,000 feet have been removed by erosion, leaving still 8,000 feet of elevation remaining. Now, if this elevation be the result of removal of weight by erosion, how is it that a removal of 12,000 feet has caused an elevation of 20,000 feet? This result is natural enough, however, if elevation was the cause and erosion the effect, for the effect ought to lag behind the cause. It is evident, then, that we must look elsewhere—that is, in the interior of the earth—for the fundamental cause, although, indeed, the effects of this interior cause may be increased and continued by the addition and removal of weight.

But perhaps the best illustration of the distinctness of the two kinds of causes of these movements is found in the oscillations of the Quaternary period. I say best because in this case the effects of the two may be disentangled and viewed separately, and this in its turn is possible because the loading in this case is not by mere transfer from one place to another, and therefore is not correlated with unloading. In fact, the elevation in this case is associated with, and in spite of, loading. The elevation, as we all know, commenced in late Tertiary and culminated in early Glacial. This elevation was, at least, one cause, probably the main cause, of the cold and the ice accumulation, but the elevation continued in spite of the accumulating load of ice. Finally, however, the accumulating load prevailed over the elevating force and the previously rising area began to sink, but only because the interior elevatory forces had commenced to die out. Then with the sinking commenced a moderation of the climate, melting of the ice, removal of load, and consequent rising of the crust to the present condition, but far below the previous elevated condition, because the elevating forces, whatever these were, had in the meantime exhausted themselves. If it had not been for the interference of the ice load, I suppose that instead of the double oscillation which actually occurred there would have been a

simple curve of elevation coming down again to the present condition, but culminating a little later and rising a little higher than we actually find it did.

The question arises as to how great an area is necessary for the operation of the principle of isostasy? What extent and degree of inequality of surface may be upheld by earth rigidity alone?

The recent transcontinental gravitation determinations by Putnam and their interpretation by Gilbert[1] seem to show a degree of rigidity greater than previously supposed. They seem to show that while the whole continental arch is certainly sustained by isostasy—that is, by deficiency of density below the sea level in that part, the continental area being lighter in proportion as it is higher—yet great mountain ranges like the Appalachian, Colorado, and Wasatch mountains show no such means of support, but are bodily upheld by earth rigidity; and even great plateaus, like the Colorado plateau, 275 miles across, are largely, though not entirely, sustained in the same way.

MONOCLINAL MOUNTAIN RANGES.

Until recently mountain ranges were supposed to be all made in one way, namely, by lateral crushing and strata-folding and bulging along the line of yielding. To Gilbert is due the credit of having first drawn attention to another type, conspicuously represented only in the plateau and basin region, especially the latter—that is, those produced by tilting and irregular settling of the crust blocks between great fissures. The two types of mountains are completely contrasted in all respects. As to form, the one is anticlinal, the other monoclinal. As to cause, the one is formed by lateral squeezing and strata-folding, the other by lateral stretching, fracturing, block-tilting, and unequal settling. As to place of birth, the one is born of marginal sea bottoms, the other is formed in the land crust. Classified by form, we may regard the two types as belonging to the same grade of earth features, namely, mountain ranges; but classified by their generating forces, they belong to entirely different groups of earth movement. The one belongs to the second group mentioned above, the other to the third and fourth groups; for the plateau-lifting, crust-arching, and consequent tension and fracturing belong to the third group or oscillatory movements, but the mountain-making proper—that is, the subsequent block-tilting and unequal settling—belongs to the fourth group or isostasy, for that is wholly the result of isostatic readjustment and is one of the best illustrations of this principle. It shows on what comparatively small scale under favorable conditions (probably unstable foundation) the principle of isostasy may act. It is evident, then, that it is impossible to exaggerate the distinction between these two types of mountains. They belong, as we have seen, to entirely different

[1] Gilbert, Phil. Soc. Washington, vol. 13, 1895, page 31; Gilbert, Jour. Geology, vol. 3, 1895, page 331; O. Fisher, Nature, vol, 52, 1895, page 433.

categories of interior forces, and, indeed, are not both mountains in the same sense at all. It was for this reason that, in my paper on mountain structure,[1] I put these latter in the category of mountain ridges instead of mountain ranges—of modification, not of formation. I now think it better to divide mountain ranges into two types, not forgetting, however, the very great distinction between them.

CONCLUSIONS.

To sum up, then, in a few words: There are two primary and permanent kinds of crust movements, namely: (*a*) Those which give rise to those greatest inequalities of the earth's surface—oceanic basins and continental surfaces; and (*b*) those which by interior contraction determine mountains of folded structure. These two are wholly determined by interior forces affecting the earth as a whole, the one by unequal radial contraction, the other by unequal concentric contraction; that is, contraction of the interior more than the exterior. There are also two secondary kinds of movement, which modify and often mask the effects of the other two and confuse our interpretation of them. These are: (*c*) Those oscillatory movements, often affecting large areas, which have been the commonest and most conspicuous of all movements in every geological period, and are, indeed, the only ones distinctly observable and measureable at the present time, but for which no adequate cause has been assigned and no tenable theory proposed: and (*d*) isostatic movements or gravitative readjustments, by transfer of load from place to place, by erosion and sedimentation, or else loading and unloading by ice accumulation and removal, and also by readjustment of great crust blocks. If the previous one (*c*) or oscillatory movements have masked and so obscured the effects of (*a*) continent and ocean basin-making, this last (*d*), isostasy, has concealed the effects and obscured the interpretation of all the others, but especially of (*b* and *c*) mountain-making forces and the forces of oscillatory movements. In fact, in the minds of some recent writers it has well-nigh monopolized the whole field of crust movements. We shall not make secure progress until we keep these several kinds of movements and their causes distinct in our minds.

[1] Am. Jour. Sci., vol. 16, 1878, page 95.

THE PHYSICAL GEOGRAPHY OF AUSTRALIA.[1]

By J. P. Thomson, F. R. S. G. S.

In an anniversary address of this kind, it seems to me a first duty to acknowledge how deeply sensible I am of the honor you were pleased to confer upon me by unanimously electing me to the distinguished position of president of this society at last annual meeting. True it is that since the foundation of the society I had always endeavored to further the interests of our cause in every possible way during many years of actual self-denial, as honorary secretary, and there was, indeed, a time during an earlier period of our history when the secretarial duties were combined with those of treasurer and librarian. But these labors were lightened and enlivened by the love and enthusiasm that inspired them, by the support of a few personal friends, and by the hope that my adopted country and its rising generation would be benefited, both educationally and commercially, by a well-established national institution for the collation and dissemination of geographical knowledge. That my fondest hopes were not altogether in vain, nor the efforts so cheerfully given fruitless is, I think, clearly enough shown by the recognized position we now occupy among the scientific and literary institutions of the world, and by the splendid collections of valuable books and maps with which our library shelves are enriched. To the honest laborer for love, whether physical or mental, no other recompense is looked for than an inward consciousness of endeavoring to do good. Still, in the case of ourselves, we may fairly claim that our efforts have been amply justified by results. It seems to be a custom, sanctioned by usage, that the president of a society such as ours should have conceded to him the privilege of delivering an address to the members at the end of his term of office. That, in fact, appears to be the last act of a drama in which he has had to play the leading part—by no means an easy one, although in this case peculiarly pleasant. In my own case it must be confessed that a difficuly was experienced in the choice of a suitable subject, not but that there are several important and even interesting ones, more or less connected with the depart-

[1] Address to the Royal Geographical Society of Australasia, Brisbane, July 22, 1895. By the president, J. P. Thomson, F. R. S. G. S., F. S. Sc. (Lond.). Printed in Proceedings and Transactions, Vol. X.

ment of geography, in which I claim to take a deep interest, but it seemed to me undesirable to retraverse fields already occupied by my predecessors. At one time a presidential address was supposed to deal more or less with the work of the society during the preceding year, pointing out at the same time what had been done in its particular department in other parts of the world, with a plan for future operations. In some societies the practice is still followed out, but in my own opinion the wisdom of such a custom is open to doubt, and it is well to consider whether it is not better to deal with some local or special subject, leaving the operations of the society to be summarized in the report of the council, and the departmental work in other parts of the world to the special treatment of the older and larger societies. In this way the provincial bodies would act as tenders or feeders to the parent societies in Great Britain and the continent of Europe, supplying them with trustworthy local material for the department of national or universal geography. Such a recognized plan of action would doubtless result in universal federation of workers in the field of geographical science. It would also lead to a more thorough and exhaustive treatment of the various departmental subjects than they at present receive, and would result in uniformly organized, concerted, and systematic action in the field of labor.

On this occasion I shall endeavor to follow in the footsteps of one of my distinguished predecessors, Sir S. W. Griffith, who, in his very learned and interesting presidential address to this society in 1891, dealt with the "Political Geography of Australia."

To the native born, and to those whose homes and family ties naturally bind us all together in a common bond of union under the Southern Cross and the other beautiful constellations of the southern sky, there is no other country on the face of the earth so dearly beloved as Australia. None is certainly more important, and it is not to our credit as a people that while our school children are crammed with what after all is only a superficial and inadequate knowledge of all other parts of the world, little attention is given to our own country, to our industries, or to our natural and artificial resources. To the credit, be it said, of a public-spirited journal the subject of our national industries has recently received special treatment, and it is hoped the Courier, to which I particularly refer, will devote equal time and attention to other phases of our partially or wholly undeveloped resources. The Physical Geography of Australia demands fuller treatment than it has hitherto received by any society of this kind, for while we are always ready and anxious to extend our investigations over wide and remote fields the needs of our own country are too often overlooked. It is no doubt true that several parts of the interior of Australia are either wholly unknown or but imperfectly known. Enormous tracts of sterile and waterless country have baffled the efforts of many travelers to investigate the inland regions, and it is only quite recently that several important dis-

coveries have been brought to our knowledge through the enlightened and patriotic enterprise of two South Australian gentlemen, Sir Thomas Elder and Mr. Horne, of Adelaide, who with praiseworthy liberality defrayed the cost of two separate and well-appointed scientific expeditions to Central Australia. The absence or scarcity of reliable information concerning the more remote parts of the continent may no doubt account to some extent for the little attention hitherto bestowed upon its physical geography as a whole. As an example of how insignificantly Australia has, until very recent years, been regarded by intelligent and well-informed Europeans, I will just quote the concluding sentence of the introductory paragraph of an article in a standard work on geography, published in 1885, by Longmans & Co., of London: "But recent events have conferred upon Australia an importance which justifies our making it the subject of a distinct chapter."

A backward glance at what we assume to be the earliest stages of evolution of our continent, through successive geological ages, will enable us to realize more fully the distinct peculiarities of its physical aspect as well as of its past and present climatic conditions, as influenced by the various progressive steps of development. Let us commence with the Paleozoic period, during which we find a few raised disintegrated fragments of a submerged plateau projecting above the surface of the ocean. In Western Australia the dry land at this stage is represented by an elongated area extending from the twentieth parallel to the neighborhood of Swan River. The western or extreme outer fringe of this fragment now lies submerged outside of the present coast line, and consequently it forms a section of the ocean bed within the limits of the 1,200 to 6,000 foot contour line. A somewhat similar upheaved tongue-shaped area extended from Melville and Bathurst islands southward into Central Australia, and, like the former fragment, its northwest edge or shoulder is now submerged in the neighborhood of Anson's Bay within the 1,200-foot contour line. The remaining continental patches above water were represented by a few superficially small and isolated narrow elevations along the eastern seaboard of the continent, distributed over an extensive northerly and southerly range from Cape York Peninsula to the Australian Alps. These insulated fragments were, according to Prof. James Geikie, the Hon. A. C. Gregory, and other well-known authorities, the earliest representatives of this continent. The climate of this and other continental divisions of the globe must have possessed a remarkable uniformity of character throughout the whole area to which reference has been made. The areas of dry land being comparatively small, offered little impediment to the free circulation of ocean currents, and thus by the commingling of polar and equatorial waters an exceedingly mild and equable temperature was maintained. The succeeding stage of evolution was marked by the somewhat rapid and wide extension and unity of land areas. Insulated fragments increased in magnitude, assuming more

truly continental proportions during the Mesozoic era. A narrow belt of dry land, corresponding to the position of the Great Dividing Range, extended along the whole seaboard of Australia, uniting Tasmania, New Guinea, and Borneo. The whole western half of the continent was likewise raised above the surface of the ocean, curving westward to Java, Sumatra, and, effecting a junction with the eastern area at Borneo, stretched northerly to the southeast portion of India.[1] Owing to this remarkable process of evolution, an enormous gulf or inland sea swept the whole central region of Australia, extending northerly and westerly to the southern shores of Borneo. The climate during this period was in like manner uniform, though less persistently marked than in earlier times. In the dawn of Tertiary times, Australia had become entirely continental or insulated. The connecting belts, which formerly uited it with neighboring counties, were submerged, and the inland waters were confined to a tract of submerged country in the neighborhood of the junction of the Murray and Darling rivers. Besides this the sea encroached upon the coast districts of the Gulf of Carpentaria, also upon a portion of the coast fringe in Western Australia, between Shark's Bay and Cape Leeuwyn, and a narrow section along the head of the Great Australian Bight was also submerged, but in all other respects the general conformation of our continent was almost identical then with what it is now. Contemporaneous with this physical change in the geographical aspect of the country a pronounced differentiation of climate occurred. Climatic zones possessing marked and distinctive characteristics existed, and in these mild seasonal changes prevailed. Although I have already remarked upon the uniformity of climate during the two preceding ages, still it seems reasonable to suppose that the atmospheric air was then more highly charged with moisture than we can at present conceive it to be, and that the rainfall in tropical and extra-tropical regions must have been enormous, owing to the widely distributed equatorial waters over vast areas of the globe, and the extensive circulation of ocean currents. It is worthy

[1] It is not by any means improbable that during this age there was actually a land connection between Australia, New Zealand, the Antarctic Continent, and Patagonia. On a map accompanying a paper read before the Royal Geographical Society, and published in the *Geographical Journal*, January, 1894, Dr. John Murray shows that these lands are connected by a submerged plateau over which the soundings are very shallow, compared with the enormous depth of the neighboring ocean bed. The strongest evidence in support of this theory is, however, to be found among the fragmentary remains of extinct animals recently discovered in these now widely separated regions. In the Chatham Islands there have been found the remains of a large ocydromine rail and the fossil bones of a coote, allied to other extinct families that formerly inhabited Mauritius, and were probably distributed over a very wide geographical range of the southern hemisphere. There is also the occurrence of struthious birds in New Zealand, Queensland, Madagascar, and Patagonia, which seems to indicate that they were scattered about at a time when there were few impediments to interfere with their migratory movements over immensely wide areas, part of which is now occupied by the waters of the South Pacific Ocean.

of note that the predominating topographical features of the continent do not appear to have undergone any remarkable change during the successive stages of evolution under review. The dominant areas of elevation in all cases correspond throughout with the mountain ranges along the eastern seaboard, the Northern Territory, and Western Australia, while the central region is still charaterized by low and extensive desert-like salt-bush plains, dotted with shallow lakes and salt pans, and traversed by inland rivers. Configuration and position of land areas are two of the fundamental agents that operate in establishing and controlling the climatic zones of our globe, while their influence upon the distribution of rainfall is simply enormous. To enable us to study and understand the people of a country it becomes necessary and indeed indispensable to investigate the physical features and climate, for no other known agents exercise so powerful an influence on the grouping and migrations of the race as these, as well as in moulding and modifying classes and racial types. As compared with other countries, there is a decidedly marked defect in the physical geography of Australia. It possesses no remarkable mountains of high elevation, although the culminating peak of the Australian Alps is capped with snow for nearly all the year round. The highest ranges border the east coast line, extending in a more or less continuous chain from Wilson's Promontory in the south to Cape York in the north. Except the McPherson's Range, this great coastal chain of ranges is practically of no value in limiting or influencing the political divisions of the country, nor yet does it afford any very great impediment to or security against invasion. In most places it is easily accessible from the seaboard, and it possesses no narrow wild passes such as those that limit the great commercial inland trade routes in Europe, Asia, and America. One remarkable feature associated with the physical condition of the southeastern part of the continent is that the highest elevations correspond very closely with and occupy a position adjacent to the greatest depth of the ocean, which approaches closer to the southeast coast line of Victoria than any other part of the continent.

The general plan or system of this eastern area of elevation may be briefly put in the following manner: From the main coastal range there radiate toward the interior numerous offshoots, or lateral spurs, as it were, and these form the watersheds of the inland rivers, as they are called, or streams that flow toward the interior. These outliers bear local designations, more or less appropriate, such as the Liverpool Range, New England Range, and Blue Mountains in New South Wales. The eastern face of the range approaches close to the coast line, and its waters are drained by several comparatively short but rapid rivers that frequently overflow their banks and inundate large areas of low-lying country during abnormal rainfalls. In Queensland there is probably a wider and more uniform distribution of elevated areas than in any other part of the continent. Here the elevations of the Coast

or Great Dividing Range, as it is locally known, vary from 2,500 to 4,000 feet above sea level. Barklay's Tableland and Selby and Kirby's ranges separate the Gulf rivers from the Georgina, Hamilton, and Diamantina streams that flow southwesterly. McPherson's Range, which forms a natural boundary common to New South Wales and Queensland from Point Danger to the junction of Tenterfield Creek with the Severn River, culminates in Mount Lindesay, 4,064 feet above sea level, but besides it there are several other high and rugged peaks along the crown of the range. Gregory Range, a lateral spur of the Great Dividing Range, divides the waters of the Gilbert and Flinders rivers. Drummond Range lies between the waters of the Belyando River and those drained by the Nogoa and Isaac streams. The waters of the Burnett and Auburn rivers are separated from those drained into the Dawson by Dawes Range, while the waters of the last stream are also divided from those of the Comet River by Carnarvon and Expedition ranges.

The country between the Great Dividing Range and the eastern coast line mainly consists of undulating and low-lying alluvial areas, with intervening river valleys abundantly watered and remarkably fertile. It is within the central and northerly parts of this division the great industrial enterprise of sugar growing and manufacture is successfully carried out and developed, it having been found that the soil and climate are eminently adapted to the growth of sugar cane on some of the coast lands of New South Wales and Queensland. West of the range the physical character of the country changes entirely. Here we meet with extensive plateaux or table-lands extending far into the interior of the continent. In New South Wales the most important of these are the Monaro Tableland; the Great Western Plains, stretching to the river Darling and into South Australia; and the New England Plateau, in the northern part of the colony. Some of these table-lands are utilized for agricultural purposes, but by far the largest portions are held for pastoral occupation.

In Queensland the western districts comprise the widely known "Downs" country, consisting of immense table land plains, interspersed with comparatively small areas of hilly and undulating country, extending far and away into South Australia. The Gulf district, or that part of the country bordering upon the head of the Gulf of Carpentaria, mainly consists of extensive plains, abundantly watered and luxuriantly grassed. Except to a very limited extent, agriculture receives but little attention within this vast geographic division, extending the whole length of the colony west of the range, although experience has amply shown that the soil and climate of the Darling Downs country is naturally adapted for the production of luxuriant crops of almost every variety of agricultural produce. Nature has endowed it with inexhaustible resources that await development at the hands of enterprising colonists. At present the country is mostly held for grazing purposes,

but its potentialities are undoubtedly great, and as settlement advances and railway communication extends and increases the whole of the western districts will doubtless be occupied by flourishing agriculturists, to whom the soil will yield all the necessary products upon which the prosperity of a country so much depends, with profit to producers and immense advantage to the country. This, in my opinion, is a very moderate and indeed limited forecast of the future of this part of our continent.

In the northern territory of South Australia there are no lofty ranges or mountains of high elevation, although the physiography of that part of the country possesses many features of great interest to geographers as well as to geologists. About Leichhardt's description of the country there seems to be some doubt, owing, it is said, to an error which unfortunately crept into the transcript of his notes. This, however, does not apply to the extensive observations made there by the Hon. A. C. Gregory, who was in a position to obtain a true and very comprehensive knowledge of the subject. Mr. Gregory's investigations show that the physical structure of this northern region consists of a moderately high and continuous table-land, very broken and extremely rugged, rising abruptly from the low-lying northern coast lands and extending southerly to Central Australia. This description is sustained by Captain Carrington, who, some few years ago, examined the rivers of the northern territory. On the other hand, exception is taken to this view by the late Rev. J. E. Tenison-Woods, who examined part of the country on behalf of the Government in 1886.

In his official report to the Government resident of the Northern Territory, Mr. Tenison-Woods endeavors to "correct the erroneous idea which has prevailed as to the physical" character of the region, pointing out that where he had been "there is no such thing as a continuous table-land." "Patches of broken table-lands occur frequently at the sources of rivers and creeks," but they are nothing more than fragments, seldom exceeding 4 or 5 miles in width and from 120 to 300 feet in height. Only once did he see a plateau of 370 feet in height. The broken edge of these table-lands always faces northerly. "The coast country is" generally "very low and flat," rising gently at the rate of about 5 feet per mile. In places there are low ridges composed of quartzite, slate, and sandstone that rise almost from the sea level to a height of 50 feet or more, gradually increasing to 100. They run northerly and southerly, trending to the eastward as they are traced to the south. Small creeks and tributaries emanate from these ridges, descending toward the permanently watered main valleys. The sources of all the waters drained to the north are in the elevated lands of the metalliferous ranges and the springs at the foot of the table-land. The features of the country change south of Pine Creek, about 150 miles from Palmerston, where there is a watershed about 800 feet above low water sea level, beyond which the water courses flow southerly and

westerly until the Katherine River is reached. This large stream then flows northwesterly, debouching into the sea as the Daly River.

The mountain system, if such it can be called, comprises the ranges in which the principal mines are found, no part of which seems to exceed 1,000 feet above sea level. The system is an isolated one, culminating in Mount Wells on the north and the country between the Union Mines and the Mary River on the south. The River Finniss cuts it off to the north.

This is the conclusion arrived at by the late Rev. J. E. Tenison-Woods, and it is no doubt a correct one in so far as it applies to that part of the country over which his examination extended, but it is believed by those who are alone competent to speak with undoubted authority upon the subject that he did not penetrate farther inland than the disintegrated coastal fringe of the great central plateau, which, according to the Hon. A. C. Gregory, undoubtedly occupies the interior of the northern and northwestern territory. This country was traversed and minutely examined by Mr. Gregory during his expedition in northwestern Australia, and to those who know how keen and careful an observer our veteran explorer is, nothing more conclusive will be required than his clear and simple statement concerning the physical structure of the country, as set forth in the Journals of Australian Exploration.

To pastoral and agricultural enterprises this Northern Territory offers most tempting inducements; the average rainfall is over 5 feet; the soil in the river valleys is remarkably rich and fertile, and immense plains carpeted with luxuriant grasses and other forms of vegetation await occupation. This description particularly applies to the country drained by the Victoria and Fitzmaurice rivers and Stuart Creek, representing an area of about 100,000 square miles. Captain Carrington, in his report upon the examination of the rivers in this part of the continent, says that "the agricultural future of this great country can only be limited by the limited faculties of mankind. Nature has apparently done everything possible."

The western part of the continent is not remarkable for high mountain ranges or for rugged peaks, although several elevated and isolated masses occur in some parts of the country, presenting a somewhat striking appearance. The Darling, Roe, and Blackwood are the principal ranges in the southwest, the first extending north and south parallel with the coast for a distance of about 300 miles from Yatheroo, in the north, to its most southern limit at Point D'Entrecasteaux. It is from 18 to 20 miles from the coast line, and its culminating point is about 1,500 feet above the sea level. East of and parallel to the Darling lies the Roe Range, whose crowning eminence is denoted by Mount William, in the Murray District. The highest peak of the Blackwood Range is only some 2,000 feet, although its average elevation is higher than that of the other neighboring ranges. The Stirling Range is the

highest natural feature in the settled districts of the colony. It rises abruptly from a low-lying coastal country, and owing to its isolated position may be seen a long way off. Ellens Peak and Mount Toolbrunup, some 2,320 and 3,341 feet respectively above sea level, mark the culminating points of this range. To the southwest of it the Porongorup Range is situated. The Leopold and Mueller ranges constitute the principal heights in the Kimberly District. Mount Amherst, the loftiest peak in the latter, is elevated some 2,533 feet above sea level. Between the Panton and Elvire rivers there is situated a hill known by the name of Mount Barratt, whose height is 2,297 feet, and Mount Coglan, on the watershed of the Margaret and Ord rivers, has an elevation of 2,084 feet.

In the settled districts the country is generally level; in places undulating, but seldom mountainous. The land on the western seaboard is also flat and the soil sandy. East of the Darling Range there is a remarkable change in the character of the country, which continues to improve as it extends inland. Vast forests of Jarrah and white and red gums occupy the whole of the uncultivated portion of the southwest districts, except a few sand plains that are here and there scattered over the face of the country.

From Israelite Bay, in the neighborhood of which is situated the Russell Range, to Spencers Gulf no high ranges or even mountains of moderate elevation exist, the only distinctive physical feature in the topography of that enormous stretch of territory along the periphery of the Great Australian Bight being a succession of sandstone cliffs from 300 to 600 feet vertical. Most of the country within this extensive region, especially north of the thirtieth parallel and west of the one hundred and thirty-third meridian, consists of immense stony and sandy desert, whose repulsive and inhospitable aspect is a significant warning to the traveler who dares to step on the border and scan the enormous expanse of eternal wildness beyond. Thick mallee scrub, spinifex sandhills, claypans, dry salt lakes (as they are strangely called), and bare, sandy plains invest the whole face of the country with a dull and painful monotony. The soil is dry and the scanty vegetation usually parched and withered, for there is little water; indeed, there is one stretch of country between Queen Victorias Spring and the Boundary Dam, a distance of 325 miles, entirely destitute of water.

The belt of country south of this region to the coast line improves vastly in character, both as regards soil and vegetation. This is especially applicable to the extensive Nullabor Plains, at the head of the bight, which are believed to be "eminently adapted in every way for pastoral purposes and probably for the growth of cereals." The large clayey deposits that exist in many places here will probably enable settlers to conserve the water, and this feature in the physical structure of the locality will, doubtless, greatly increase the value of the country as settlement advances. The Nullabor Plains extend for about 250 miles

from east to west, their northern limit being unknown. They are luxuriantly grassed and have been crossed at times when "the long line of camels left a track behind them in many places as there would be if they had passed through a cornfield." The map of the coastal district west of these plains is annotated with such brief descriptions as "Low level country covered with dense thickets and scrub, and apparently salt lakes and marshes, the horizon appearing from the southward level and uniform as the sea." "Clear open grassy country." "From this point vast plains of grass and saltbush with scarcely a tree on them, extending as far as the eye can reach in every direction." "Very gently undulating grassy country. Limestone formation 300 feet above the sea." Northerly and easterly of these plains the geological formation appears to be granite covered with sand. The granite outcrops occur in many places, and it is interesting to note that the only permanent water for many miles in any direction seems to be at a range where the granite ends and the limestone formation begins.

In the southeastern districts of South Australia the general physical aspect of the territory affords a pleasant contrast to that of the country to the north and northwest. Here are located several prominently marked areas of elevation, denoted by the Mount Lofty, Flinders, Hummocks, and Gawler ranges. Of these, the first extends from Cape Jervis northerly about 80 miles to the Little Para River, its culminating point, Mount Lofty, being 2,334 feet above sea level. This range, which follows the general course of the Murray River to the thirty-fourth parallel of latitude, is flanked on the eastward for about 20 miles by a chain of ranges of less prominence, extending from Encounter Bay in broken masses to Ulooloo, a distance of nearly 200 miles, and including the following conspicuous points: Mounts Magnificent (1,372 feet), Barker (1,681 feet), Gould (1,753 feet), Rufus (1,807 feet), and Bryan (3,065 feet); the Burra Hill (2,018 feet), Kaiserstul (1,973 feet), and Razorback (2,835 feet). Smaller ranges, Barossa, Julia, Princess Royal, and Never Never, lie to the north of Mount Lofty Range.

The Hummocks or Barunga Range commences on the west side of Gulf St. Vincent, about 10 miles from the head, and runs northerly for 60 miles to the Broughton River. South Hummock, Black Point, and Barn Hill are its most prominent features, the first being 1,064 feet high.

Flinders Range commences on the Broughton, a little southeast of the termination of the previously named range, and runs northerly by way of Mount Remarkable (3,178 feet), The Bluff (2,300 feet), Mount Brown (2,200 feet), Mount Arden (2,750 feet), and St. Marys Peak (3,900 feet) for about 200 miles, having steep spurs to the west and less elevations on its eastern side. Among the last are the Wonoka, Wilpena, Elder, Chace, and Druid ranges. It then continues in a northeasterly direction by Mount Serle (3,000 feet) and Freeling Heights (3,120 feet) to Mount Distance for 120 miles farther.

The Gawler Range is an irregular group of hills, commencing about 50 miles west of Port Augusta and extending westerly for about 150 miles more. The highest points in it are Mounts Miccolo, Nonning, Sturt, Double, Yardea, and Yarlbrinda, none of which exceed 2,000 feet above sea level.

Under the name of Musgrave Range are usually included the Everard, Mann, and Tomkinson ranges and the Deering Hills, all situated in Central Australia between the one hundred and twenty-ninth and one hundred and thirty-third meridians, and forming a belt 250 miles by 25 miles, lying east and west along the twenty-sixth parallel. The highest points are Mounts Woodroff and Morris (each about 4,100 feet high), Ferdinand (4,000 feet), and Everard (3,850 feet). To the north of these is another central belt lying northeast of Lake Amadeus and known as the McDonnell ranges, extending east and west along the twenty-third parallel. Besides these principal highlands there are several isolated volcanic peaks at the head of Discovery Bay and many other hills of less prominence in the central portion of the country.

From the preceding remarks it will be readily understood that most of the South Australian territory consists of vast grassy plains, some of which are flanked by the mountain ranges for fully 300 miles north and south, and extensive belts of undulating timbered country, the latter comprising some of the richest agricultural land in the colony, especially that situated between St. Vincent's Gulf and the Murray Scrub and in the fertile district of Mount Gambier. A very large portion of the country stretching along both sides of the Murray River is an immense waterless scrub, occasionally interspersed with open grassy plains, while enormously large areas of sandy desert and saltbush country occupy the far interior in the neighborhood of Lakes Amadeus and Eyre.

In the foregoing an attempt has been made to describe briefly the dominant areas of elevation as indicated by the mountain systems of our continent. These are certainly unique in their way, and the somewhat remarkable features that they possess invest the topography of the country with a striking peculiarity which does not occur elsewhere. As I have already remarked, the mountain ranges are, with one single exception, practically of no value whatever as natural national boundaries, nor even for the purpose of forming provincial lines of demarcation. On the other hand, their influence upon the commercial development of the country is great, for they limit settlement in a large measure to the coastal districts, offering few facilities for the extension of agricultural and industrial enterprises to the central regions. This is especially the case along the eastern part of Australia, where the massive vapor clouds, impinging upon the seaward face of the ranges, deposit most of their moisture before the western and central districts are reached, and consequently the latter do not enjoy an adequate rainfall. True, the future holds out more encouraging prospects to intending settlers than the past, for we are assured on the authority of

Mr. R. L. Jack, Government geologist for Queensland, that to the artesian water supply of the western part of that colony there is practically no limit. In his recent elaborate investigations into the geological structure of that part of the country Mr. Jack appears to have satisfied himself that the "water-bearing beds of the Lower Cretaceous formation" are far more extensive than had formerly been anticipated. The superficial area in which they occur is estimated at 5,000 square miles of Queensland territory alone, and more extensive examination will very probably show that they are far more widely distributed in other parts of the interior of the continent than Mr. Jack's recent investigations have shown them to be. The physical structure of the country is certainly favorable to this view, and if it be found that these water-bearing beds actually occur over the whole area formerly occupied by the great inland sea by which our continent was severed from north to south, the barren desert country of Central Australia will no longer bid defiance to the extension of British enterprise and settlement.

As far back as 1863 the late Rev. J. E. Tenison-Woods, in a paper read at the meeting of the British Association at Newcastle on-Tyne, on "The rivers of the interior of Australia," drew attention to the favorable conditions of the central basin for the formation of artesian wells, and in 1866 the same view was strongly advocated in a series of papers which that well-known authority contributed to the Australasian. Later on Mr. Tenison-Woods pointed out that—

"In the central depression of the Continent and in North Australia there is a line of groups of thermal and cold springs covering several hundred square miles. These send forth water from great depths, and are no doubt derived from a central underground reservoir whose sources are on the slopes of the tableland. That the waters come from great depths is seen from the fact of the temperature and the mounds of sinister or travestine around them."

Of course no artesian water supply, however extensive, can equal in value a natural one, nor yet will it ever take the place of a regular and abundant raintall; still, it will operate as an enormously powerful factor in the development of the natural and artificial resources of the country, and it is hoped that recent investigations will be followed up with equal success in other parts of the Continent, to the manifest advantage of our pastoral and agricultural industries and national prosperity.

In addition to what I have said regarding the influence of our continental highlands upon the distribution of rainfall and settlement, it must also be pointed out in this connection that the only true river system of the country is so regulated and controlled by the peculiar physical structure of the mountain ranges of the southeastern part of the Continent that few of the rivers themselves are of any value as great commercial highways from the sea to the interior. On the eastern coast most of the streams are short and traverse areas of steep declivity. During periods of heavy rains their capacity is inadequate to carry off the

surface waters and consequently they overflow their banks, inundating the low-lying country and causing great destruction of property—sometimes even loss of life. The larger rivers flow inland from the coast range and disembogue on the eastern shores of the Great Australian Bight; while some actually discharge their waters in the interior of the country into large shallow lakes or wide marshes.

The Murray, with its giant tributary, the Darling, is preeminently king of Australian rivers, and in point of "navigable length" it is, according to the estimate of Mr. H. C. Russell, entitled to rank "third amongst the navigable rivers of the world." It is, however, only right and proper to point out that this is not a fair comparison. From a geographical standpoint it errs greatly on the side of exaggeration, for while it may be true that the Darling River is navigable from Walgett to its junction with the Murray River and thence by that stream to the sea, a total length of some "2,345 miles," the assertion itself furnishes no adequate estimate of the actual capacity of the channel for the purpose of navigation. As an inland stream for navigation the Murray River[1] is of considerable importance, and the immense value of its water supply for irrigation canals can scarcely be overestimated, but at present it can not be utilized as a great commercial highway from the sea to the interior, and for this reason alone no comparison can be drawn between it and many other shorter and minor streams of the world. The shallow entrance to the river and the comparatively insignificant volume of water that passes through the channel in dry seasons are enormous obstacles which may possibly be removed at some future time when the country is more closely settled and its commercial and industrial resources more generally developed. Free and uninterrupted navigation from the sea to Walgett and from the sea to Albury would exercise a greater and more permanent influence upon the future prosperity of the country and its potentialities than it is within the power of anyone to conceive, and if that were once accomplished the Murray would rightly be entitled to rank among the first navigable streams of the globe. The total drainage area of the Murray River as recently determined by Mr. H. G. McKinney, M. Inst. C. E., is 414,253 square miles, equal to about a seventh of the area of the entire continent, and as large as the combined areas of France and Germany. This is the twelfth largest river basin of the world. Of this enormous area 234,362 square miles are situated in New South Wales, 104,575 in Queensland, 50,979 in

[1] The Murray River is here referred to as the primary water course with which are united the Darling, Murrumbidgee, Lachlan, and other tributary streams, with their numerous affluents, the whole constituting the Murray River system. In speaking generally of the first, the others are, therefore, included unless otherwise stated. In a published diagram showing the comparative lengths of the great rivers of the world the Darling is indicated as the primary stream and the Murray as one of its principal tributaries. This is certainly erroneous, for so long as the channel from the sea to Wentworth is known as the Murray River the Darling, which unites with it at the latter place, can not be otherwise described than as a tributary of it.

Victoria, and 24,387 in South Australia. The whole basin is divided into two unequal areas—an effective or contributing area of 159,889 square miles, with a mean annual rainfall of 25.03 inches, and a noncontributing area, or that which either contributes nothing to the river system or which contributes only during exceptional floods, of 254,364 square miles. The mean annual rainfall over the latter does not exceed 17.15 inches. The largest noncontributing area of 158,863 square miles lies within the colony of New South Wales, comprising a tract of country east of the Bogan and Darling, an extensive region bounded by the Darling, Murray, Murrumbidgee, Lachlan, and Bogan, and the territory west of the Darling. The whole drainage area of 24.387 square miles within the territory of South Australia contributes nothing to the river system; here the mean annual rainfall is only 16.83 inches. The delta lands and other noncontributing areas of 36.835 square miles in Queensland lie chiefly along the southern boundary of the colony within the counties of Belmore, Carnarvon, Cassillis, and along the middle basin of the Warrego River, the mean annual rainfall over that part of the country being about 18.97 inches. The area of 34.279 square miles in Victoria that contributes nothing to the river system is a strip of country south of the Murray and west of Morong, where the mean annual rainfall is something like 17.85 inches. Most of these noneffective areas consist of immense alluvial plains and gently undulating country where the rainfall is very small and uncertain; the soil is remarkably rich, and, if irrigated, would be highly productive. There is a mean annual rainfall of 20.19 inches over the whole drainage area of the Murray River. Considering the enormous extent of the watershed, the sectional areas of the primary river and its chief tributary are insignificant. The mean average discharge of the River Darling at Bourke is equal to about 6,557 cubic feet per second, and the approximate mean height of water level for a period of twelve years was 10 feet. The mean average discharge of the Murray River equals 2,791 cubic feet per second at Euston, 6,336 at Modina, and 3,516 at Albury. The approximate mean height of water level at the same places for 1879–1890 was 15.6, 16.10, and 12.10 feet, respectively. At Albury the discharge of the Murray very rarely falls below 1,000 cubic feet per second, even in the driest seasons.

The primary source of the Murray River proper is in the western face of the Australian Alps at the union of two lateral spurs, by which it is flanked on the east and west, about 20 or 30 miles north of Mount Kosciusko, whose peak of 7,256 feet above sea level marks the culminating point of the great southern cordillera. It flows southerly between these spurs or mountain ranges, skirting the northwestern base of Kosciusko, where it sweeps toward the northwest and joins the Indi River, whose source is within the Victorian territory. The entire length of the Murray is about 1,700 miles, but there is a remarkable discrepancy between writers upon this subject—it being indeed

almost safe to state that no two authorities agree upon the point at issue. The head of the upper valley of the river is characterized by the presence of a network of tributary streams or feeders, spreading out like the branches of a great tree, through whose sharply sloping and precipitous channels the thawed waters of the snow-capped ranges sweep in mighty torrents to the lower regions of the valley. Chief among these are the Mitta Mitta, Ovens, and Goulburn water courses. The physical aspect of this part of the country is wild and rugged, heavy snowstorms, violent gales, and blinding sleet being the ruling climatic features of this great Alpine chain, whose western and northern waters cut deep into the granitic and metamorphic rocks of the range, forming steep and precipitous gorges, yawning chasms, and tortuous channels, ever deepening by the erosive action of the troubled waters of many streams. The Murrumbidgee, although one of the tributaries of the Murray, is little inferior to that stream itself. Emanating from its source in the elevated table-land at the base of Peppercorn Hill, some 5,000 feet above sea level, it traverses a tract of country possessing some remarkable features of natural beauty, especially in its upper valley, where the mountains are steep and rugged and the lateral valleys deep and precipitous.[1] Below this region the river flows through the celebrated Riverina district, where its flood waters often spread out over large level areas in the neighborhood of numerous shallow water courses which act as local distributors. In seasons of severe drought it is nearly dry in some parts of the channel, even as far down as Hay, where the bottom is sandy and consequently highly absorbent. The total length of the Murrumbidgee is 1,350 miles. Its principal affluent is the Lachlan, a stream of about 700 miles in length, rising in the rugged western spurs of the Great Dividing Range, north of Lake George. The highest part of its watershed is about 3,000 feet above sea level, where snow seldom falls in sufficient quantity to materially influence the flow of the river. The lower valley embraces long stretches of level plains, interspersed with belts of stunted gum, mallee, and saltbush, and in dry seasons the channel of the stream is indicated by a mere chain of water holes.

With outspread arms of unequal length that extend far and away to sources remote from the parent stream, the river Darling drains the western and southern waters of the Great Dividing Range from the head waters of the Lachlan to a place slightly north of the twenty-fifth parallel, where it is met by Buckland's table-land. Here the watershed inclines in a somewhat irregular curve westerly and southwesterly, following the Warrego Range to a point northeast of Mount Edinburg, which marks its northwestern limit. Within the periphery of this circumscribed region are included the waters of the Bogan,

[1] About a year's sojourn in this part of the country and on the head waters of the Snowy River gave the writer an excellent opportunity of observing the physical structure of the locality and its climate.—J. P. T.

Macquarie, Castlereagh, Namoi, Gwyder, Macintyre, Weir, Moonie, Condamine, Mungallala, Maranoa, Warrego, and Paroo sources. The Warrego unites with the Darling about 65 miles below, and the others, except the last, about 10 miles above Bourke. Although included within the drainage area of the Darling, the Paroo terminates in swamps some two score miles northwest of Wilcannia, consequently its waters never reach the main stream, and it is only during exceptionally heavy floods that the latter receives any of the Warrego River waters. Including its longest tributary, the Culgoa or Condamine, whose source is in the western flank of Wilsons Peak (4,032 feet), in the neighborhood of Killarney, the total length of the Darling River is about 1,953 miles to its junction with the Murray at Wentworth, thence to the sea through Lake Alexandrina for 587 miles. In his paper upon "The rivers of the interior of New South Wales," Mr. F. B. Gipps estimates the length of the Darling River at 1,953 miles, and Mr. H. C. Russell states that it is 3,282. The discrepancy is certainly remarkable, and in the interests of correct geographical information it is here pointed out.

I have already drawn attention to the importance of the water supply of the Murray River system for irrigation purposes, and to the enormous extent of country within its basin that could be rendered highly productive by irrigation. This matter, I am happy to say, is now engaging the attention of the Government of New South Wales, where a water conservation department has recently been established, and in a few years we may expect to see the beneficial results of this wise and enlightened policy everywhere apparent in the country west of the Dividing Range.

Along the southern and eastern continental seaboard are numerous rivers, few of which are, however, of any great commercial importance as compared with those of other parts of the world.[1] In Victoria the Glenelg drains the western waters of the Grampians and those of the Victoria Range. From its source in the northeastern spurs of the latter it flows westerly and southerly through a most devious channel for 205 miles, discharging its waters in Discovery Bay, near the western boundary of the colony. It drains an area of about 4,500 square miles. At the southeastern corner of the continent the Mitchell and Snowy rivers flow into the Pacific Ocean. The former rises in the southern face of the Great Dividing Range, emptying itself into Lake King, and the sources of the latter are within the colony of New South Wales in the lofty Kiandra ranges. The length of its channel is about 400 miles, and its drainage area some 5,000 square miles. Next in point of geographical position and importance are the Hunter and Clarence rivers, north of Port Jackson. The former from its source in the Liverpool Range flows south and east for 200 miles to the port of Newcastle. It

[1] As most of these streams are too insignificant to merit separate treatment here, reference will only be made to such as are of special importance.

drains an exceedingly fertile basin of 7,900 square miles of the finest pastoral and agricultural land in the whole colony, and large steamers and other vessels navigate its waters for a distance of some 35 miles, besides one or two of its tributaries, which are also navigable. The Clarence is certainly one of the finest streams of eastern Australia, although the entrance is obstructed by a bar. From its source in the Obelisk Mountains to the sea in Shoal Bay it flows through a channel of 240 miles in length, draining a fertile valley of 8,000 square miles. It is navigable from the sea up to Copmanhurst for 67 miles. The district is famous for its mineral areas and for its rich agricultural and pastoral lands. The Brisbane, Fitzroy, and Burdekin rivers are such as to merit something more than mere passing notice. From a commercial standpoint the first, taken in order of position, is undoubtedly the most important stream with which we have to deal on the eastern coast of the continent. It rises in the most northerly extension of Cooyar Range, north of Mount Stanley, and flows in a general southerly and easterly direction through a very crooked channel for 210 miles to Moreton Bay. It combines with its own the united waters of the Stanley, Bremer, Cooyar, and other tributary streams, by which it is so greatly augmented during periods of heavy rain that many of the low-lying areas within its basin are seriously flooded. It drains an area of 5,300 square miles, including that part of the East Moreton district bounded on the northwest by the Main and Cooyar ranges; on the southeast by the watershed of the Logan River; and on the northeast by the D'Aguilar Range. The flourishing and rapidly rising capital of the great northern colony of Queensland is situated on the banks of this river, about 15 miles from its mouth. It is navigable to Brisbane for the largest steamers, and for small vessels as far up as Ipswich. The Fitzroy is a large and important stream 180 miles long, with about twelve tributaries. It is navigable for large vessels for 40 miles, to the town of Rockhampton, and drains an area of some 55,600 square miles of country. The Burdekin River is a large stream of 425 miles in length, draining an area of 55,529 square miles, whose tropical waters are discharged in the Pacific Ocean at Upstart Bay. It is not, however, navigable, except for small vessels, a few miles only, and during heavy floods the channel is liable to undergo much alteration. The delta lands are exceedingly fertile, but the river itself is of little value for commercial purposes. The subsoil is porous and the surface soil very rich. The whole of the lower basin is eminently adapted for tropical agriculture, and the areas of the delta are highly productive sugar lands, most of which are under cultivation and yielding remarkably heavy crops of cane of a high density. In times of heavy floods the low-lying lands are inundated by the overflow of the river waters, but the deposit of sediment left on the surface considerably increases the fertility of the soil. In the northern part of the continent there are several remarkably fine rivers, some of which are of considerable

importance, especially the Victoria and Roper. The former is a splendid stream, the Murray of this side of the continent, disemboguing into the Indian Ocean, latitude 14° 40′ south; longitude, 129° 21′ east. Its mouth is 26 miles wide, the main entrance being Queens Channel, through which it is navigable for the largest ships for fully 50 miles from the sea, and for light draft river vessels some 60 miles farther, to a place where our veteran explorer (Hon. A. C. Gregory) at one time camped for several months. The river is easy to navigate, even by strangers, the principal channel being wide and deep, with few impediments. The Victoria drains an extensive tract of magnificent pastoral country of the richest quality, comprising an area of about 90,000 square miles; of this it has been observed by early travelers that there is a greater luxuriance of grass than had been met with in any other part of the world. The whole of the basin is abundantly watered by a copious tropical rainfall, and there are no elements of uncertainty in the climatic features of the region. In comparing this magnificent commercial highway with other famous streams of the world, Captain Carrington, who surveyed it in the Government steamer *Palmerston* in 1884, writes that, "in view" of "its capability as a harbor and its easiness of access," he has "no hesitation in saying that the Victoria is far superior to the Thames, Mersey, or Hooghley." No stream in the northern part of the continent is perhaps more widely and better known to early colonists than the Roper River; it has been oftener frequented than any of the other streams, especially at the time when the overland telegraph line was being constructed, the stores and material for the northern portion of which were landed there. It is a long river penetrating far into the interior and is navigable for vessels drawing from 10 to 12 feet for over 90 miles from the sea. Its waters are discharged into the southwest part of the Gulf of Carpentaria, in the immediate neighborhood of Maria Island, the coast being at this place very flat, with a wide fringe of mangroves and extensive shallow patches of mud and sand. From the sources of its more distant tributaries, in the central portion of the Northern Territory, it flows almost due east to the sea. Besides these there are several other large and important northern streams, especially the Adelaide and Daly rivers. The former flows through a splendid pastoral country, luxuriantly grassed, and is navigable for 80 or 90 miles by vessels of 10 or 12 feet draft. It takes its rise in the neighborhood of Pine Creek Railway Station, on the overland telegraph line, and discharges its waters into Adam Bay at Clarence Strait. The latter stream may be navigated by river boats for some 60 miles from the sea, into which its waters are discharged at Anson Bay. It is a long river with several widely expanding tributaries, and it traverses an extensive tract of country, including some fine agricultural and pastoral lands, and there are valuable copper mines near the navigable portion of its channel.

Owing to the absence of high mountain ranges and on account of the

peculiar physical structure of the country, there are no rivers of importance in the western part of the continent. True there are some of the streams of from 300 to even 500 miles in length, such as the Fitzroy, Ashburton, Gascoyne, and Blackwood rivers—the first three flowing into the Indian Ocean and the last into Flinders Bay. But these are only developed into true continental streams during periods of very heavy rains, when enormous volumes of water rush through their channels to the sea, sometimes overflowing the banks and flooding extensive areas of low-lying country. In dry seasons they are greatly diminished in size, the main channels being quite shallow and of little value as commercial highways. The Fitzroy drains an extensive tract of country, comprising considerable large areas of very fertile land. The Ord River is a large stream: its source is in the ravines of the Albert Edward Range, near the western edge of the Great Antrim Plateau and Denison Plains, in the neighborhood of Kimberley; thence it flows almost due north to the shores of Cambridge Gulf, a short distance west of the mouth of the Victoria River. The country in the neighborhood of the head waters of the Ord is very rugged and exceedingly difficult to travel. None of the rivers are navigable except the Swan for about 20 miles.

The whole coast line along the entire periphery of the Australian Bight is the most remarkable region with which we have to deal in this description of the river systems of the continent. There are no prominent or conspicuous physical features along this part of the coast line, and the geographer may look in vain for anything approaching a well-defined stream of water. Nor is this at all singular when we glance at a general map of the country and see the enormous extent of level plains and desert areas by which it is chiefly characterized. Except a long narrow belt of sandstone cliffs with which the coast line is distinguished there are no prominent features to relieve the eternal monotony of this dry and uninhabited region. The rainfall here is very light, uncertain, and capricious, and falling on an intensely hot and loose sandy surface it evaporates with remarkable rapidity before soaking any great depth into the soil. For this reason there is an almost entire absence of surface water, and consequently nothing to form or maintain running streams.

Most of the so-called rivers of South Australia are torrents in winter, but mere creeks or successions of water holes in summer. In the settled portions of the province many of them take a westerly course to St. Vincent and Spencer gulfs, and a few by a southerly course empty themselves into Encounter Bay, and have their sources in ranges trending in a northerly direction. In the northern portion, Lake Eyre, an enormous basin below sea level, receives the surplus water brought down from the east by the Cooper or Barcoo; from the northeast by the Warburton and Diamentina; from the northwest and west by the Macumba and Neales, respectively, and from the south by the Frome.

All these large water courses are filled to their utmost capacity during wet seasons, but in dry years they have only a little permanent water in them.

Lakes.—Most of the so-called lakes of Australia are insignificant depressions filled with the storm waters of widely expanding river channels during heavy rains. In the central regions these are spread out over extensive shallow basins, usually surrounded by a thick deposit of mud, whose surface is characterized by a hard and treacherous saline crust. Located in vast, rainless, saltbush country, where the heat is intense, the flood waters evaporate with astonishing rapidity, and for most part of the year these lakes are simply enormous mud basins, where salt is deposited in large quantities. During the rainy season they are again filled by the flood waters of inland rivers. The largest are lakes Eyre, Amadeus, Gardiner, Torrens, Frome, and Gregory, all more or less salt. The configuration of the continent is not favorable to the formation or existence of large natural reservoirs for the storage of permanent fresh water in the inland regions, such as are to be found in New Zealand and other countries where deep lake basins occur in mountain regions and on high table-lands. Formed, as Australia is, like the inverted half of a gigantic bivalve, with the eastern part high and dipping more rapidly toward the center than the western half, which gradually and imperceptibly slopes inward, most of the inland basin is flat, the soil and upper stratum highly absorbent, while the lower portion of the bed in several parts is not much, if indeed at all, above sea level. For this reason, and in view of the general physical structure of the continent as a whole, I regard the theory of subterranean channels, through which it is believed that large volumes of rain water find their way to the sea, as altogether erroneous. No leakage of sufficient magnitude to compensate for the somewhat rapid disappearance of the flood waters of some of our inland rivers, in my opinion, exists, and the convenient supposition, for such it really is, that the few and insignificant submarine springs between Cape Otway and the mouth of the Murray River are indicative of such, arises more from a preternaturally excited imagination than from a just conception of the fundamental law of hydrology. Several so-called leakages no doubt occur along some parts of the coast line, oozing through the porous strata or in the form of bubbling springs, such as may be met with along the shores of most of the Pacific islands, but the necessary evidence to sustain the theory that large volumes of fresh water are discharged into the ocean through subterranean channels is not at present available.

Flood waters are usually highly charged with sediment that is held more or less in suspension while they pass through channels of steep declivity, but which is rapidly deposited over areas where the minimum velocity occurs. The primary effect of deposition is experienced in the rapid or gradual silting up of water channels, and consequent diminu-

tion in their carrying capacity. Viewed in this light, it seems to me improbable that any system of subterranean channels could always remain effective along comparatively low levels. Against this opinion it may be stated that the flood waters filter through the upper strata and are thus freed from sediment before the lower levels are reached. But this is not by any means conclusive, for the efficiency of filter beds is liable to become impaired or altogether ineffective by heavy deposition of sediment and superincumbent or internal pressure. As previously remarked, the central basin of our continent is characterized by an almost uniformly low depression, in places actually below sea level, over which the flood waters of our inland rivers spread out in immense shallow sheets, but through which it is scarcely possible they can gravitate to the sea in opposition to the local hydrographical conditions. Throughout these central catchment areas an absolute deposition of sediment occurs, and most of the waters rapidly disappear by the simple process of evaporation. On higher levels, where the waters pass over or are collected on highly absorbent cretaceous beds, some are retained, from which our artesian supplies are probably derived; but even here a very large percentage is lost by evaporation, which, in my opinion, is of itself sufficient to compensate for the speedy drying up of shallow water holes and river beds.

Along the eastern seaboard there are several natural reservoirs of fresh water, such as Lakes George and Bathurst and other smaller basins, inappropriately called lakes, but which in reality are merely lagoons. These are, however, comparatively shallow; even the largest has been known to be quite dry in times of severe and protracted droughts. The most remarkable and at the same time unique of all the Australian lakes is that which occurs in the alpine regions of Gippsland. Situated in one of the recesses of a lofty range culminating in Mount Wellington, 5,000 feet above sea level, is a beautiful lakelet known by the native name of Tali-karng, whose height above sea level is about 3,000 feet. Mr. A. W. Howitt, who examined it in 1890, concluded that the basin of the lakelet has been formed by an accumulation of rock fragments that fills the valley of Nigothoruk Creek, and thus dams up the water, which does not overflow the embankment even in times of flood. It is about 100 feet in depth in the deepest part; the surface is pear-shaped, and it covers an area estimated at about twenty-six acres.

Climate.—The potent influence of climate upon the inhabitants of a country as well as upon its natural and artificial resources renders its consideration essential in dealing with the subject of physical geography. Notwithstanding the rapid development of Australian meteorology during recent years, resulting chiefly from the widely scattered ramifications of the Queensland weather office, under the enthusiastic direction of Mr. Clement Wragge, the climate of our country as a whole has not yet been satisfactorily elucidated, although the older estab-

lished offices at Sydney, Melbourne, and Adelaide have for many years given much attention to the subject. Thanks to the enlightened policy of the Queensland government, much indeed has been done in recording atmospheric phenomena at numerous stations spread out over an enormously wide field, extending even outside of what is usually considered the geographical limits of Australasia proper. But no fundamental law has yet been established by which the meteorologist can foretell any remarkable seasonal changes by which our pastoral and agricultural industries are so largely influenced; nor yet, indeed, has any satisfactory explanation been given of the probable cause of protracted droughts or seasons of maximum rainfall. Meteorology, it is true, is yet in its infancy, in this part of the world at least, and if an elucidation of our climatic changes is to depend upon an accumulation of recorded data rather than upon abstract scientific principles based upon deductive premises, then a generation of observers must pass away before we can hope for any satisfactory results. In this connection an interesting and vitally important subject awaits consideration. I refer to the influence of our Australian climate upon the European inhabitants of the country, and more especially upon the native-born Anglo-Australian. In this land a distinct austral branch of the race has been planted, and nothing can be more interesting than to note the extent of climatic influence upon the physique and natural characteristics of that race. The geographical position of Australia places it within the influence of two powerful atmospheric zones of unequal temperature. Two thirds if not the whole of the continent is more or less affected by the widely circulating equatorial air currents that frequently sweep down upon our shores with rapidly developing energy across the Indian Ocean. These strike our seaboard with enormous cyclonic force, carrying with them great dense masses of vapor clouds that condense and empty themselves in the form of heavy precipitations, which cause abnormal floods over the low-lying face of the country. As it is natural to suppose, the northern or tropical division of Australia is more largely influenced by these equatorial disturbances than the other portion, although at times their extreme southern limit reaches a high parallel of latitude. On the other hand, we are sometimes, although less frequently, visited by the cold antarctic disturbances that overlap extensive southern areas of our country. That the climate of this part of the continent is influenced by the south polar air and ocean currents there can not, I submit, be the slightest doubt, and an exhaustive investigation of this subject is of the most vital importance to science and commerce. Toward the solution of this interesting problem much will doubtless be done by a more extended acquaintance with the antarctic regions when further exploration of far southern latitudes is accomplished. The presence of enormous masses of polar ice in Australian waters in close proximity to the shore is not by any means an uncommon occurrence, and when it is considered how com-

paratively narrow the belt is that separates us from the actual northern limit of the antarctic ice drift we will probably admit that there is some affinity between our own climate and that of far southern lands. There is also a probability that the recently discovered traces of so-called glaciation in our own country is not an indication of a true glacial period at all, but simply isolated fragments of southern ice masses which, having drifted far away into northern regions when there were much smaller and fewer land areas to impede the circulation of Antarctic Ocean currents, stranded on the southern shores of a partially submerged continent during a period of rapid evolution, when the predominant physical conditions would favor the preservation of traces for ages. Be this as it may, the significant fact remains that the only traces discovered have been found in the extreme southern portion of our continent and on the neighboring island of Tasmania—a circumstance which, in my opinion, strongly favors the theory of ice drift. The great extent of our continent and compactness of its land mass invest it with a very wide range of climate. There are three distinct and primary zones—tropical, subtropical, and temperate, and these may be subdivided into local divisions, representing the climates of our seaboard, the mountains, tablelands, and the great central desert area. On the whole the tropical climate of Australia is not by any means unhealthy to Europeans. On some of the low-lying coastal areas in the immediate neighborhood of swampy and marshy lands malarial fever is readily contracted by people who are not acclimatized and by those who rashly expose themselves. The subject is a difficult one with which to deal; so many contributing causes have to be considered—physical condition, food, clothing, mode of life, and other predisposing factors require special elucidation before the extent of absolute climatic influence can be properly estimated. Individual opinion, and indeed individual experience, is not by any means a satisfactory guide in investigating this subject, for men's opinions, like their physical conditions, rarely harmonize. Mr. E. A. Leonard, who spent some time in the Cardwell district land surveying, says: "The climate is very trying to white men, who must rapidly deteriorate in physique should they live there continuously." There are many people who concur in this opinion. On the other hand, Mr. A. Meston, who has had a long experience in widely different parts of the country and who gives an interesting chapter upon the subject in his recently published valuable work, regards the tropical climate of northeastern Australia in the most favorable light, maintaining that it is exceptionally healthy to Europeans. Unjustifiable prejudice has much to do in a case of this kind, but taking all things into consideration I am inclined to believe that continuous domicile in any tropical climate is not favorable to perfect health, viewed from an Anglo-Saxon standpoint; and this is especially so in the case of females. There are certainly periods of uncomfortable inertia that seem to insinuate themselves even upon those who are physically healthy, and these have a

tendency to increase rather than diminish. Many of the old troubles associated with early pioneer colonization have partially or almost wholly disappeared with the advance of settlement, and many localities that were formerly considered unhealthy are not so now, and Europeans of temperate habit can live in tropical Australia in the enjoyment of very good health with little discomfort. It should, however, be borne in mind that a tropical climate is never salubrious, except on elevated positions.

Within the temperate zone the climate varies greatly with the latitude, and it is, moreover, governed very much by extent of elevation and other local configuration of physical conditions. In the southern and southeastern portion of the continent the climate is cool and remarkably healthy throughout the year, except two or three months of the summer, when the temperature is abnormally high and hot winds more or less prevalent. Along the seaboard of this division the atmosphere is rarely free from moisture, and this element of discomfort is experienced more keenly on the low-lying and deltaic lands of river valleys, where the alluvial soils absorb and retain a larger percentage of the rainfall than on the neighboring undulating tracts of country where a good natural drainage exists. On the table-lands of the New England, Monaro, and other districts the climate is at all times salubrious; and in the upland mountain regions of the southern Alpine chain, the Blue Mountains, and Liverpool Range the cold is acutely felt in winter, and during the summer months the atmosphere is sharp and bracing. In the great central basin of the continent the atmosphere is dry and intensely hot; there is little or no rainfall, and most of that part of the country is a vast, arid desert, altogether uninhabitable. The western plains of New South Wales are remarkably fertile for grazing purposes, notwithstanding the scanty rainfall, and with a good supply of artesian water the soil is eminently suitable for agriculture. The Riverina climate is famous for its healthfulness, especially for those with weak chests, the atmosphere being exceedingly dry and the temperature uniformly high. In Queensland the Darling Downs and western districts possess the finest climate of Australia. For consumptives and those with weak respiratory organs it is unequaled anywhere, and there are numerous instances on record of cures having been effected in this part of the country where cases were considered hopeless. In summer the atmosphere is extremely dry and hot, but never oppressive. The winter months are delightfully cool and bracing—light frosts sometimes occurring, but never severe nor of long duration. The climate here is in all respects on a parallel with that of Italy. For some unaccountable reason, most probably arising from prejudice and ignorance combined, the climate of the East Moreton district is often supposed to be uncomfortably hot and enervating. That such is not the case may easily be proved by reference to the records of the chief weather bureau and to the vital statistics of this

part of the colony. The three or four summer months are naturally hot, but there are no sudden changes at any time; there is a remarkable uniformity of temperature; the nights are comparatively cool and hot winds entirely unknown. In winter the weather is most delightful, the climate then being even superior to that of Naples; beautifully clear sky and dry atmosphere are the ruling climatic features of this season of the year in southeastern Queensland. The only slight discomfort felt is during the westerly winds, which are seldom of longer duration than three days. From the early days of settlement on the shores of Moreton Bay the climate of the district has always been considered exceptionally healthy. In The Geographic History of Queensland the author quotes an interesting extract bearing upon this subject from a report written in 1845 by Dr. Keith Ballow to the Rev. Dr. Lang. Dr. Ballow, who had spent some eight years in Moreton Bay as Government medical officer, says: "The district of Moreton Bay is altogether an extremely healthy one, there being only a few deaths from disease of any kind. The climate in the winter season is one of the finest in the world. This district is not a profitable field for doctors." This seems to be the general verdict of those who are qualified to express an opinion upon the subject. The most important factor of our Australian climate is that of rainfall. Land without an adequate rainfall is useless for either pastoral or agricultural purposes unless artificially watered by irrigation. Although the total area of the continent is about 2,944,628 square miles, a vast portion of that area has an annual rainfall of less than 10 inches, and consequently it is of little or no value whatever in its present state. This is notably the case with the great central depression where immense areas of waterless desert country obtain. Considering its compactness and wide climatic range, the rainfall of Australia is very unequally distributed over the whole of the territory, even in places where there is a regular wet and dry season. A glance at the rainfall map will readily show that this is indeed very marked along the eastern Pacific slope, where the greatest pluvial measures have been recorded. The Cardwell and Mackay districts top the score, the former with an average annual rainfall of some 150 inches; Arnhems Land follows with about 63 inches; the Australian Alps, the Tweed and Mary rivers come next, each with 50 inches. These isolated and somewhat limited areas are, however, distributed over a wide geographic range, extending from the most northern to the southern limits of the continent, and they are separated by extensive tracts of country or climatic zones, over which the average annual rainfall is not greater than 30 inches. In the Cardwell and Mackay districts, which lie wholly within the tropical rain belt, the former between the parallels of 15 and 20 degrees, the isopluvoise lines of 40 to 70 inches are very closely packed together, so that the heavy rains in these zones seldom extend beyond the Coast Range, but are mostly precipitated over the deltaic lands of the river and valleys and on the Pacific slope of the

Dividing Range. In these districts there is a regular wet and dry season—the former occurring in the months of December, January, and February, when the atmosphere is heavily laden with moisture and the shade temperature, of from 80 to 90 degrees, exceedingly oppressive. During this period there is a prevailing northeast wind, which changes to southeast and continues in that quarter throughout the remaining nine months of the year. In the Cardwell district the tropical scrubs sometimes ascend the ranges to a height of over 2,000 feet, where the temperature is lower than that to which they properly belong, but such cases only occur where the volcanic soils are exceptionally rich. In Arnhem's Land, or all that high table-land portion of the Northern Territory of South Australia north of the sixteenth parallel, the annual rainfall averages about 60 inches, and is more equally and generally distributed than in any other part of the continent; the climate is, of course, tropical, but the mornings and evenings are generally cool, and the usual discomforts of the moist atmosphere of the low lying eastern and northern coast lands are not felt here on the dry upland zone of the plateau. A remarkable feature of the prevailing Australian climate is found in the rapidly diminishing rainfall after crossing the Great Dividing Range of the southern and eastern cordillera. There is an immense belt of country comprising the western plains of New South Wales and Queensland; Cape York Peninsula; the whole of the country bordering upon and extending far south from the head of the Gulf of Carpentaria; most of the southern portion of the Northern Territory of South Australia, and the Glenelg and Kimberley districts of the western portion of the continent, where the average annual rainfall does not exceed from 10 to 30 inches. Except in the extreme southwest corner of Australia, where the isopluvoise lines of 20 and 30 inches are fairly well established, the rainfall of the western division is very scanty, being limited to a narrow belt along the seaboard, where it only averages from 10 to 20 inches. In the Murchison and Gascoyne districts extremely heavy dews occur, which, no doubt, compensate to some extent for the lack of an adequate rainfall. In the northern part of western Australia the wet season commences in December and usually ends in March, and it is during this period the destructive cyclonic storms are experienced. These are of the true equatorial type and move along with enormous velocity, often causing great destruction to property and not infrequently loss of life. The wet season of the southern district is from April till October, during which time most of the annual rainfall is recorded. The climate here is temperate and in every respect congenial to Europeans; fruits and agricultural produce are plentiful, and the forests yield an abundance of very valuable timbers. In the Kimberley district the heat of the summer months is intense, but during the cool season the climate is agreeable. In some of the northern districts the temperature, although very high, is not by any means inimical to health, as the atmosphere is remarkably free

from moisture and the heat less oppressive than in other parts where the humidity is great and the thermometer lower. On the table-lands of the interior of this part of the country the climate during the greater portion of the year is delightful, but of the far eastern or central districts little is known beyond mere report, which in most cases is unreliable.

South Australia is not by any means an abundantly watered colony, the rainfall being probably less than in any other part of the continent. In the neighborhood of Adelaide there is some 20 to 30 inches annually, the average record being about 22 inches only, in the wettest districts; while the country occupied by the Flinders Range, Eyre's Peninsula, and that along the shores of Spencer's Gulf enjoys but a scanty rainfall of little more than from 10 to 20 inches annually. In this country, too, the excessive heat and persistent droughts are keenly felt during the summer months of the year. Augmented by the heat from the sandy desert plains of the interior the atmosphere is sometimes oppressive and hot winds very trying both to animal life and vegetation. From these, which usually occur in the months of December, January, and February, there is absolutely no escape, the temperature being abnormally high and not infrequently the thermometer rises 110° to 115° F. in the shade. Luckily these only occur during three months of the year, the winter season being mild and agreeable.

Some interesting and useful information might be given concerning the pastoral and agricultural resources of our continent did time and space permit. In both respects I have, I fear, already exceeded reasonable limit; I will therefore merely offer a few remarks which, if they do nothing more, may call attention to these vitally important subjects. A good pastoral country requires an adequate water supply, either derived from rainfall or from artesian sources. The former is natural, inexpensive, and permanent; the latter costly and limited. The wants of the pastoralist and agriculturist are unequal, although both are equally dependent upon the products of the soil. Grass or any other form of vegetation can only grow in soil where there is sufficient moisture to sustain it, and this necessary want can only be supplied, naturally, by rainfall. The more uniformly it is distributed throughout the year the better will the country be for pastoral occupation. On the other hand the agriculturist requires sufficient rainfall during six months of the year, but his crops of grain and his vines would be little affected if the other six months were rainless. But too much rain is injurious to grain crops, for while it requires more than 20 inches of rainfall in the summer for maize, such a climate would be unsuitable for the successful cultivation of wheat. To the agriculturist nothing is more important than climate, and reliable information upon this vital subject is essential to the successful cultivation of the soil, both here and elsewhere. Although Australia is preeminently a grazing country, there are nevertheless extensive agricultural areas where grain crops may be

profitably raised. In the eastern part especially there is a long belt stretching northerly from Jervis Bay along the coast to Broadsound, where the rainfall is more than 20 inches during the summer months, which is there the rainy season. Here there is an extensive climatic zone, lying between the twenty-second and thirty-fifth parallels, favorable to the cultivation of maize. Outside of this region, including all the coastal country from Adelaide north to Toowoomba, the rainfall is more than 10 inches during the six winter months, which represent the agricultural season there. These are simply the natural agricultural regions in eastern extra-tropical Australia, or that part of our territory where the climate is favorable to the cultivation of maize and wheat. In many other districts there are enormous areas of rich soil whose highly productive qualities could be profitably utilized by irrigation were adequate means provided for the conservation of water. But this is a subject upon which little attention has hitherto been bestowed, although it is of the most vital importance to the nation and one which can not be much longer neglected if the resources of our country are to be adequately developed.

In this address I have attempted to give as concise and, at the same time, comprehensive an account of the physical geography of our continent as it is possible for me to do under the circumstances. The subject is a vast one with which to deal in any form, and the smallest of our colonies could easily have furnished abundant material without exhausting the rich source of supply. Its chief merit is that it is based upon the most recent information, derived from official sources, and in this respect it is reliable and trustworthy, the writer having aimed at these rather than mere literary style or elegance of diction. Appended is a selection of what will no doubt be considered useful information, but which could not be conveniently included in the narrative portion of this address without making it unnecessarily ponderous. It consists of schedules of our principal rivers and mountains; the lengths, drainage areas, etc., of the former, and heights of the latter. The preparation of these has entailed a great deal of labor, but it was thought that the data would be useful for educational purposes and serviceable to my successors, who will thus be supplied with available information to enable them to follow up this interesting and vitally important subject.[1]

In conclusion I desire to acknowledge my obligations to the Hon. A. R. Richardson, M. L. A., commissioner of crown lands, Western Australia; to Mr. William Houston, under secretary for lands, Sydney, and to Mr. William Strawbridge, surveyor-general of South Australia, for valuable information specially prepared by them for this address.

[1] The schedules referred to are here omitted.—Editor.

ARCTIC EXPLORATIONS.[1]

By Rear-Admiral A. H. MARKHAM.

The subject on which I have been deputed to address you to-day is that connected with arctic explorations. It is, I venture to assert, a very fitting and appropriate one to discuss before an International Geographical Congress such as this, because the question of polar research, more especially in the north, is, and has been for more than three hundred years, one of world-wide, and consequently of international interest. Nations have vied with each other in their laudable endeavors to further the great cause of geographical discovery, and a very friendly rivalry has existed, and I am pleased to think still continues to exist, between various countries, with the view of advancing their respective flags over the threshold of the known region into the interesting and mysterious unknown. This is a spirit that should be fostered and encouraged, for it is one that has done much in the past to promote the interests of geographical science all over the world.

It is not my intention to occupy your time and attention with a detailed narrative of geographical events connected with the arctic regions as they have occurred in regular chronological order, or of the results that have been achieved by the various successive expeditions that have been dispatched with the object of exploring those regions, for these are oft-told tales, and are sufficiently well known to those who are interested in polar research. My object to-day will be briefly to survey the threshold of the unknown region—a region, let me remind you, that embraces nearly a million and a half square miles, to dwell lightly on the latest work that has been accomplished up to that line of demarcation that separates the known from the undiscovered area, and to review generally the prospects of success of future arctic exploration, concluding with a short summary of the various scientific results likely to accrue by the continuance of such work.

I will preface my remarks by alluding briefly to those nations which have in the past particularly interested themselves in north polar discovery. They are Great Britain, the United States of America, Austria-Hungary, Sweden, Germany, Russia, Holland, and Norway.

[1]Address before the Sixth International Geographical Congress, London, July 26–August 3, 1895. Printed in Report of the Congress, pp. 177–201.

Perhaps the merit of having delineated the greatest amount of coast line on our north polar maps rests with this country, but it is only fair to add that this satisfactory result is, in a very great measure, due to the excellent geographical work that was achieved by those various expeditions that were dispatched by England, during the period embraced between the years 1849 and 1859, with the object of searching for the missing Franklin expedition.

The United States of America have, principally through the munificence and patriotism of its citizens (nobly supported as they have been by the energy of those who have been employed), been wonderfully successful in their laudable efforts to reveal the hidden secrets of the unknown north.

To Austria-Hungary we are indebted for the discovery of a large extent of territory which has been called Kaiser Franz Josef Land.

To Sweden, thanks to that distinguished scientist and arctic explorer Baron Nordenskiold, belongs the undying honor associated with the successful accomplishment of the northeast passage along the north coast of Europe and Asia from the Atlantic to the Pacific.

Germany has successfully traced the east coast of Greenland to as far north as Cape Bismarck, in latitude 77°.

Russia has done admirable work by a very complete survey of the seaboard of Novaya Zemlya, as well as by the delineation of the coast of the mainland from the Kara Sea, around Cape Chelyuskin, to Bering Strait.

Holland has, by successive expeditions sent up year after year (the dispatch of which was mainly due to the active exertions of the late Admiral Jansen), done much to familiarize us with the condition and drift of the ice in the Barents Sea, even as far as the shores of Franz Josef Land.

And, finally, Norway claims Fridtjof Nansen as a countryman, who won his spurs as an arctic traveler by the indomitable pluck and energy he displayed during his marvelous journey on snowshoes across the icy continent of Greenland, and who is now combating, and let us hope successfully, with the almost insuperable difficulties attending an enterprise the main object of which is to carry his vessel across the extreme northern point of our globe.

It will thus be seen that many nations have shared in the glorious work of arctic discovery, and all of them have written their names, some with perhaps a stronger hand than others, on the pages of arctic history.

A glance at the map will at once reveal the fact that there are several ways by which this large unknown area of a million and a half square miles can be approached.

In the first place, there is the route via Smith Sound, by which we have penetrated a greater distance into the unknown area than in any other direction. There are also the approaches by Jones Sound and

Wellington Channel; the exploration of either of these is likely to lead to important and valuable results. Thirdly, there is the way by Spitzbergen. Fourthly, by Franz Josef Land, where at the present moment the English Harmsworth expedition, under the command of Mr. Jackson, is prosecuting its researches. Then there is the route selected and adopted by Nansen in the neighborhood of the New Siberia Islands. And, lastly, there is the way by Bering Strait.

I now propose discussing the merits of some of these approaches with reference to their applicability to future polar research.

We will commence with Spitzbergen, a group of islands easily reached during the course of an ordinary summer cruise, and even in vessels that are not specially constructed for ice navigation. This ease of accessibility and comparative immunity from danger from the ice is due to the warm water of the Gulf Stream, which, flowing northwards as far as the eighty-first parallel of latitude, becomes eventually absorbed in the north polar current; but before this absorption takes place its influence has been felt along the entire west coast of Spitzbergen, thus rendering the navigation of those waters comparatively easy and safe.

Although, I think, it is an undoubted fact that Spitzbergen was sighted by the Dutch navigator, William Barents (who, however, supposed it to be a part of Greenland), the credit of its discovery has invariably been awarded to that grand old sailor, Henry Hudson, whose high latitude, reached nearly three hundred years ago, was unsurpassed for more than two hundred years, until, in fact, that prince of Arctic navigators, Sir Edward Parry, reached, with the aid of boats and sledges, 82° 45′ north, in 1827.

There is a very marked difference between the nature and conditions of the ice, as experienced by Sir Edward Parry and others, to the north of Spitzbergen and the ice in other parts of the Arctic regions in similar or even in much lower latitudes. North of Spitzbergen the ice fields are of great extent. The floes are comparatively level and smooth, and consist apparently of ice of only one season's formation, whereas the ice that has invariably been met north of Smith Sound and Bering Strait and in the vicinity of East Greenland and Franz Josef Land has been of the same heavy, massive character as that to which Sir George Nares very appropriately applied the term palæocrystic, i. e., ice of ancient date, probably the formation of centuries. This leads one to the supposition that a very large extent of ice-covered sea exists to the north of Spitzbergen; a sea, however, that receives the warm but gradually cooling water of the Gulf Stream, and is, therefore, antagonistic to the formation of heavy or perpetual ice. But these large ice fields are in a measure dominated by the north polar current after the disruption of the pack in the summer, and under the influence of this stream they are drifted bodily to the southward. It was this constant southerly drift that was the cause of Parry's failure to reach a higher

latitude than that which he succeeded in attaining, for he found, to his chagrin, that he was being drifted to the south with greater rapidity than he was making progress to the north.

Success in this direction may, however, be achieved by dispatching exploring parties with sledges and boats in the early spring, before the disruption of the pack has taken place. This would, however, necessitate a ship passing the winter on the north coast of Spitzbergen. With Parry's valuable experience to guide them, I am confident they would find no difficulty in surpassing that great navigator's highest position, with every prospect, perhaps, of the discovery of land to the northward. If my anticipations prove correct, then valuable and important results will be obtained by an expedition sent to explore in this particular direction.

Mr. Leigh Smith has, in addition to other good geographical work in this neighborhood, attempted to circumnavigate the Spitzbergen group, but so far this feat has not yet been achieved, nor has the position of that somewhat mysterious island named on our charts Gillis Land ever yet been reached. It was sighted and named in 1707 by the Dutch captain, Cornelius Gillis (or Giles), but he did not land on it. Its position, as given by this navigator, was, however, placed on Van de Kuelin's map, published in 1710. In 1864 it was reported to have been sighted by Captain Tobiesen, but he was unable to effect a landing. Some geographers endeavor to identify it with Wiche's Land, which was recently sighted by Mr. Leigh Smith from a high hill in Genevra Bay, in Stor Fiord, Spitzbergen. I am inclined to think that what Captain Gillis saw—if he saw land at all, which is perhaps doubtful—was an extension of Franz Joseph Land, the nearest known point of which is, after all, not more than about 120 miles from Spitzbergen. Wiche's Land is situated too far south to be mistaken for Gillis Land, if the latitude of the latter place is approximately correct on the chart. It is not, I think, at all improbable that a chain of islands extends between Gillis Land and Franz Joseph Land.

While treating of Spitzbergen, I may mention that the latest scheme by which the mysteries of the unknown region surrounding the north pole are to be revealed to us comes from Sweden, for we are given to understand that it has been proposed to undertake a voyage from Spitzbergen to the pole in a balloon. But as I understand that Mr. Andrée, the originator of this enterprise, will communicate a paper, on his proposed expedition, to the congress, I will not further allude to it, except to assure him of our heartiest wishes for the success of his plucky and novel adventure.

We now come to Franz Josef Land, which comprises a large territory, but whether a continent or archipelago remains a geographical problem for further elucidation and solution. The history of the discovery of this land by the Austro-Hungarian expedition, under the joint command of Weyprecht and Payer, in 1873, reads more like a romance than a

commonplace, prosaic record of ordinary geographical discovery. It will be in the memory of all here how their ship, the *Tegetthoff*, was beset in the ice on August 20, 1872, off the west coast of Novaya Zemlya on the very day and only a few short hours after they had said farewell to Count Wilezek, Baron Sterneck, and other friends on board the little sailing cutter *Isbjorn:* and how, notwithstanding the powerful aid of steam with which their vessel was provided, and the free use of gunpowder, they failed to release the imprisoned *Tegetthoff*, and how she remained immovably fixed in the fetters of her icy bondage, drifting about in the floe at the mercy of winds and currents for two long years. Then suddenly, on August 31, 1873—a year after their first besetment—a mysterious dark land loomed up to the northwestward, and they thus became unwittingly and without any exertions on their part the discoverers of a new territory, the existence of which had hitherto been unknown, to which they gave the name of Kaiser Franz Josef Land.

The drift of the *Tegetthoff* during the period she was beset in the ice was no less remarkable than it was instructive. Her position when first caught by the ice in August, 1872, was in latitude 76° 22′ and longitude 62° 3′ east. Six months afterwards she was in latitude 78° 45′ and longitude 73° 7′, showing that the whole body of the pack in which she was beset had been carried steadily during that period in a northeasterly direction. For the next nine months her drift was in a north and northwesterly direction, until the ship became permanently stationary by the adherance of the ice to Wilezek Island. Altogether the drift of the ship, and consequently the pack, was somewhat over 200 miles to the northeast between August, 1872, and February, 1873, and about the same distance in a northwesterly direction from the last-named date until the ice remained fixed by attachment to the shore on November 1, 1873. Some of this drift may be attributable to the wind, but the real movement was assuredly due to the influence of current alone. During the sixteen months that the ice was in motion—i. e., from August, 1872, until November, 1873, inclusive—I find that for a period of six months the prevailing wind was from the southeast, for five months it was from the northeast, for two months from the northwest, and for three months from the southwest. During the six months she was being drifted in a northeasterly direction the prevailing winds were from the southwest and southeast, and during the last nine months of her drift the winds may be described as all round the compass. Therefore we can not, I think, do otherwise than arrive at the conclusion that the wind had but little effect on the drift of the ice, either with regard to rapidity of motion or direction. What, then, was the cause of this marvelous drift to the northward? We know very well that the general drift of the north polar current is in a southerly direction. We have had convincing proofs of it in a remarkable manner down the east coast of Greenland, down Smith Sound and

Davis Strait, into Baffins Bay, and through Bering Strait. The inference must therefore be that the movements of the ice in which the *Tegetthoff* was beset must have been influenced, and in no slight degree, first of all by that warm current of water which I have already alluded to as expending itself along the west coast of Spitzbergen, and a portion of which must find its way into the Barents Sea; and, secondly, by the large volumes of water which are discharged from those great Siberian rivers the Yenesei and the Ob. Unlike my friend Nansen, I do not think that the influence of these large rivers can be felt at a greater distance than about three or four hundred miles from the mainland. The theory of their flowing in a direct northerly line across the pole is, I think, open to question, for it appears to me to be opposed to all authenticated information that has hitherto been obtained, and is antagonistic to our preconceived notions and ideas as to the extent and direction of what is known as the north polar current.

The discovery of the Austrians was of the greatest geographical importance, and the value of it was materially enhanced by the plucky sledging expedition that was carried out by Payer during the spring of 1874. I say plucky, because when Payer left his ship for a contemplated absence of thirty days he was not at all sure that he would find the *Tegetthoff* in the same position as when he left her. A gale of wind, or the disruption of the ice during his absence, would very likely occasion the drifting away of his ship, which would render his chances of escape very small indeed. Fortunately, no such contretemps occurred, and he returned to the *Tegetthoff* rich in geographical and other scientific information. During his journey he succeeded in ascending Austria Sound, between Zichy and Wilczek lands, to the latitude of 82° 5′ in Crown Prince Rudolf land, about 160 miles from the position in which he had left his ship. From this position land, called Petermann Land, after the celebrated geographer of Gotha, consisting of high, conical-shaped hills, apparently of volcanic formation, was seen to the northward, and estimated to be in about or beyond the eighty-third parallel of latitude.

Since the discovery of Franz Josef Land our knowledge of it has been much increased by the results of the voyages of Mr. Leigh Smith in his steam yacht the *Eira*. Without encountering very much opposition from the ice, he succeeded in sighting the land on August 14, 1880, on about the fifty fourth meridian of east longitude; that is to say, some 60 miles to the westward of Wilczek Island. Steaming to the westward, exploring the coast carefully as he proceeded, Mr. Leigh Smith passed the south point of land, and succeeded in crossing the forty-fifth meridian of longitude, when he found the coast trend away in a northwesterly direction, certainly as far as the eighty-first parallel of latitude. His further progress was stopped in latitude 80° 19′ by ice, and he was compelled to abandon further research in that direction. During the voyage Mr. Leigh Smith discovered and explored at

least 110 miles of new coast line, besides obtaining a very interesting and valuable collection of natural-history specimens from a portion of the globe that, in a scientific sense, was almost unknown; for it must be remembered that the collections obtained and preserved by the members of the Austro-Hungarian expedition were unfortunately lost when their ship was abandoned. Several peculiarities were observed in the physical conditions of the country, differing in some respects from other Arctic lands. For instance, the islands seen were in almost all instances crowned with ice caps, while the icebergs that were observed were invariably flat-topped. The drift of these bergs appeared to be to the north: but I do not think that too much reliance can be placed on the observations that led to this conclusion, as they were necessarily of a somewhat perfunctory character. Mr. Leigh Smith, after leaving Franz Josef Land, made a gallant attempt to reach Wiches Land from the eastward, but he found the ice so densely packed as to defy all efforts to penetrate it, so he returned to England.

It is, I think, very probable that Franz Josef Land will be found to extend to a considerable distance to the northward; Mr. Leigh Smith found it to extend, at any rate as far as he could see, to the northwest. It is not at all impossible that it also extends in an easterly direction, and I think that we may very reasonably conclude that Franz Josef Land, as a whole, will be found to consist of a large continent intersected by numerous fiords and large glaciers, or else an archipelago consisting of many large islands. The exploration of this little-known land, and the determination of its extent and character, are well worthy of serious consideration, and would be productive of the most useful and valuable scientific results. In the following year Mr. Leigh Smith made another voyage to Franz Josef Land, with the object of continuing his exploration of the previous year, but unfortunately his little vessel was crushed by the ice off Cape Flora in latitude 79° 56′, and he and his men were compelled to pass the winter in those inhospitable regions. They found it a comparatively barren and sterile shore, but fortunately bears and walruses were obtained, which very materially supplemented the provisions they succeeded in saving from the wreck. When the ice broke up the following year, with the aid of their sledges and boats, they happily succeeded in reaching the coast of Novaya Zemlya, where they were succored and brought home by the steamer *Hope*, which had been specially dispatched in quest of them under the command of Sir Allen Young.

Taking all things into consideration, Franz Josef Land appears to me to be the region to which our efforts should be directed with a view to further exploration, offering, as it does, the most likely prospect of achieving the greatest amount of geographical success. For here we have all those elements that are essential to successful exploration in high latitudes—namely, a coast line affording facilities for sledge traveling, a continuity of land trending in a northerly, northwesterly, and,

for all we know to the contrary, in a northeasterly direction, the very directions in which we wish to proceed. Having this continuity of land, no difficulties exist for the establishment, in absolute security, of depots of provisions and stores for the use of traveling parties. From the configuration of the known land we may reasonably infer that good and sheltered harbors may be found in which a ship, or ships, can winter without any anxiety being felt by those on board on the score of being blown away or crushed by the ice (indeed, we already know of one snug little haven discovered by Mr. Leigh Smith, and named by him Eira Harbor, admirably adapted for such a purpose); and, a very important matter, we know that abundance of fresh food in the shape of bears and walruses, and possibly reindeer and birds, can be obtained.

I have, therefore, no hesitation in advocating the adoption of this particular route as being the best, according to our present lights, for future polar exploration. From a careful study of the character and formation of the land explored by Payer, I venture to predict that Franz Josef Land will be found to extend as far as the eighty-fourth parallel of latitude, and possibly even beyond the eighty-fifth; but, of course, this is purely conjectural on my part, and must be accepted for what it is worth. But whether the land extends as far as I have indicated, or whether it comes to an abrupt termination in latitude 83°, very valuable results will accrue, both geographically and geologically, by an investigation of its interior and the examination of its coast line.

Although I have implied that conditions favorable to successful exploration are to be found by using Franz Josef Land as a base of operations, still it is only right for me to add that no precautions should be omitted to insure the safe return of the explorers, for exploration in the polar regions must always be attended with a certain amount of risk to those engaged on a service that is perhaps at all times somewhat hazardous. With this very important object in view, I consider it is absolutely necessary, in the event of an expedition being sent in this direction, that a large depot of provisions and stores should be established, either at Eira Harbor or on the northwest coast of Novaya Zemlya—somewhere, I would suggest, in the vicinity of Cape Nassau—as being the most conveniently situated place that a retreating party from Franz Josef Land would make for, and the easiest to reach. Then, again, I am one of those who do not quite approve of a party being left entirely dependent on their own resources; that is to say, without a ship at their back. The terrible sufferings and experiences of those who, in former days, have been left unsupported fully illustrate, not only the desirability, but the absolute necessity of having a ship so situated that she may be regarded as a safe refuge always to be found, provided with a plentiful supply of provisions, and having on board the wherewithal, in the shape of boats, sledges, clothing, stores, etc., to equip a retreating party; and although she may, as

in the cases of the *Investigator* and the *Tegetthoff*, be irrevocably frozen in the ice, she is, at any rate, replete with everything that will add to comfort, and that will conduce to a successful retreat when the time comes to abandon her. The very knowledge of having a ship as the base of operations imparts a moral courage and feeling of confidence and contentment to the men that it is desirable to foster.

From what I have said, I do not wish it to be inferred that sledge traveling along the shores of Franz Josef Land will be found to be a very easy task. On the contrary, I think it will abound with difficulties, and although I consider that the traveling during the early spring will not prove more arduous or more difficult than has been experienced along other Arctic shores, I can not but help thinking that extra caution will have to be observed in order to insure the safe return of the traveling parties in the summer. Payer tells us that the land in the direction in which he traveled was intersected by deep fiords, and that he passed numerous glaciers with terminal faces of 100 feet in precipitous height from the sea. It is the passing of these glaciers, and the entrances of these fiords, that I fear will be extremely hazardous, even if it is not found absolutely impossible in the summer, unless a long detour into the interior is made, so as to cross at the head of the glacier or fiord. For if the land ice—i. e., the young ice of the previous winter's formation adhering to the coast—has broken up (and it would probably be so by the breaking away of large fragments of ice from the terminal face of the glaciers, or the flowing out of the ice from the fiords) a sledging party, unless provided with a boat, would find its retreat cut off by water, and in order to return to their base of operations they would be under the necessity of extending their journey a considerable distance, and this, perhaps, with their provisions nearly expended, and their own strength materially diminished by the arduous work they had already gone through. I merely mention this as what may possibly be the experience of any party engaged in the exploration of Franz Josef Land.

The next important question to be decided is the exact route that should be adopted by the explorers. Should they turn all their energies to the west coast, or, following in the footsteps of Payer, should they attempt to push up Austria Sound? I unhesitatingly record my opinion in favor of the first-named course, and for the following reasons: The western shores of all Arctic lands of which we have any knowledge are always more accessible in a ship, and to a very much higher latitude, than the eastern coasts. Vessels have penetrated to the eighty-second parallel of latitude along the west coast of Greenland, but navigation along the east coast of Greenland has invariably been impeded by the accumulation of heavy ice 500 miles to the south of the position reached on the west side. The same may be said of Spitzbergen and of Novaya Zemlya, and I see no reason why it should not hold good for Franz Josef Land. Indeed, Mr. Leigh Smith has already demonstrated the

feasibility of a steamer reaching, with comparative ease, a somewhat advanced position along the western shores of that land. I do not think it probable, from Payer's account of the state and condition of the ice in Austria Sound, and from the absence of all harbors, that that inlet would lend itself to successful navigation for a ship to any great distance, although perhaps well adapted for exploration by means of sledges; but I do not think that a well-found steamer, competently commanded and efficiently equipped, would, without very much difficulty, succeed in crossing the threshold of the unknown region along the western side of Franz Josef Land, where a snug and sheltered position could be found, in which she might be secured for the winter, whence traveling parties could be dispatched for further exploration, resulting in the certainty of the accomplishment of good, useful, and important work.

On the whole, then, I am strongly in favor of Franz Josef Land as the base for future operations, for it seems to me that in this direction there are better prospects of pushing into the unknown area. It gives promise of yielding the most abundant harvest in the various fields of science, while, with proper precautions, absolute safety to the explorers can be assured. These are, of course, reasons of the greatest importance when the question of the be stroute for polar exploration is under discussion, and I am confident they will be found to outweigh all other advantages that are likely to be considered in favor of other routes.

At the present moment our thoughts, not unnaturally, are directed to this particular portion of the Arctic regions, by the remembrance that it is only twelve months ago that an English expedition, under the leadership of Mr. Jackson, but organized and equipped under the supervision, and entirely at the expense, of Mr. Harmsworth, sailed from our shores in the little steamer *Windward* with the object of exploring Franz Josef Land and, if possible, the regions beyond. We are still ignorant as to the progress that has been made by Mr. Jackson, for no tidings have been received of him and his brave companions since they bade farewell to civilization a year ago and steamed away toward the north. They have selected the right direction in which to proceed, and I look forward with confidence to hearing, in a very short time, that they have succeeded in penetrating into the unknown area, and are doing good and useful geographical as well as other scientific work. They have our best and heartiest wishes for a successful issue to their undertaking, and a happy return to their friends when their work is accomplished. Geographers owe a debt of gratitude to Mr. Harmsworth for initiating, and for having so generously and so patriotically provided the means for defraying the cost of this expedition.

With regard to what I may call the region to the east of Novaya Zemlya, no one has done more to advance geographical science in this direction than that distinguished Swedish Arctic explorer, Baron Nordenskiold. He, by dint of several expeditions that he made to Spitz-

bergen, and by tentative voyages of reconnoissance through the Kara Sea and as far as the mouth of the Yenesei River, qualified himself to achieve what has so long baffled the navigators of earlier ages, the accomplishment of the northeast passage. This he performed in 1878–79, by rounding the most northern point of the old world, sailing along the northern coasts of Europe and Asia, and thus passing by sea from the Atlantic to the Pacific. This splendid achievement must be regarded as one of the greatest geographical feats of the present century; not only was it of exceptional interest from a geographical standpoint, but it proved to be of the utmost value and importance to every other branch of science. A knowledge of the geological formation of the various countries situated in high latitudes is indispensable, in order to enlighten us with reference to the early history of the earth. Nordenskiold's researches in this particular branch of science, together with his observations on physical geography, ethnology, natural history, meteorology, and terrestrial magnetism, are replete with interest; nor must I omit to mention the very valuable dredgings that were made at the bottom, which were found to be exceedingly interesting and important.

Nordenskiold sailed, it will be remembered, in the summer of 1878, in the steamship *Vega*, under the command of Lieutenant Palander of the Swedish navy, who had been his companion in some of his former expeditions. On August 19 they reached Cape Chelyuskin, the extreme northern point of the old world where, contrary I think to expectation, he found the depth of the water to increase somewhat rapidly to 124 meters at a distance of about 8 miles from the cape. On the 27th, in spite of fogs and mist, he passed the mouth of the Lena, and three days later sailed to the southward of the New Siberian islands. Eastward of this the sea was so free of ice that for three days they were able to push on at the rate of 150 miles a day. On September 3 they passed Bear Island, and on the 6th Cape Chelagskoi was reached; thence their progress was much impeded by loose ice. On the 12th they were abreast of North Cape, but from this time onward great difficulties were experienced in forcing their way through the ice, besides being seriously handicapped by the gradually shortening days and correspondingly lengthening nights. On the 28th they had to acknowledge, to their great mortification, that further progress for that year was impossible and the ship was accordingly secured in winter quarters, although they were aware that only a few miles of sea—but, alas! it was an ice-blocked sea—lay between them and the open water in Bering Strait. They had been running a race against time, and had only been beaten by a few days—indeed, it may be said by a few hours only. Two days after the *Vega* was released the following year she passed East Cape, and steamed into the Pacific Ocean.

In reviewing what has been accomplished in this particular part of the Arctic regions, we must not forget the valuable services that have

been rendered to geography as well as to commerce by Capt. Joseph Wiggins, who has made, since 1874, several voyages along the northern shores of Europe and Asia to and from the Ob and Yenesei rivers. The persistent endeavors of Captain Wiggins to establish trade between Europe and Central Asia by way of the Kara Sea, are deserving of the highest commendation.

The discovery of that solitary island called "Einsamkeit," by Captain Johannesen, situated in latitude 77° 40′ and in 86° east longitude, is of the greatest importance and significance, as indicating the presence of land hitherto unknown in that direction. Although it received the name it now bears from Captain Johannesen, a name signifying "lonely" or "solitary," it seems to me exceedingly unlikely that it will prove to be so perfectly isolated as it is supposed to. Bears, walruses, and seals, besides many kinds of birds, were seen on this island, which would lead to the assumption that it might be the southern termination of a chain of islands situated to the eastward of Franz Josef Land. It is almost a pity that Johannesen did not venture to explore in a northerly direction after the discovery of this island, instead of steering to the northwest, more especially as he reports that there was very little ice about. Perhaps our knowledge of this particular neighborhood will be added to, and we will hope considerably, on the return of Nansen, who has now either commenced his return journey, or else is thinking of making the necessary preparations for passing his third winter in the far north.

It will be in the recollection of all at this Congress that in 1893 Fridtjof Nansen sailed with the object of reaching the North Pole, having conceived what, in the belief of the majority of Arctic authorities, was a very novel method of carrying out his views. Having carefully studied the direction of the currents in the north polar regions, especially the drift experienced by the Austro-Hungarian expedition in 1873, and that of the U. S. S. *Jeannette*, which was caught by the ice in latitude 71° to the southeast of Wrangel Land in 1880, and also those various well known drifts in a southerly direction through Smith Sound and along the east coast of Greenland, he arrived at the conclusion that if the currents flow from the North Pole in the direction of Greenland they must, in a corresponding degree, flow toward the North Pole on the opposite side of the Northern Hemisphere; and if vessels have on various occasions been carried by the ice to the southward, other ships similarly situated must, cæteris paribus, be drifted to the north, if they can only hit off the current at the proper locality. This if is, of course, the crux of the whole matter. By a very elaborate but somewhat one-sided reasoning, hardly, I opine, borne out by established facts, Nansen assumes that a ship jammed into the ice in the immediate neighborhood of the New Siberia Islands would drift bodily with the pack to the northward, over the North Pole, and thence to the south, eventually to be released on reaching the Atlantic Ocean in the vicinity

of the east coast of Greenland. My friend Nansen is a man who has the courage of his own convictions, and he has boldly set out in his little *Fram* in order to test the accuracy of his theory. It is, however, a theory that does not find favor with men of science in this country or with Arctic authorities generally, who, from practical experience, have laid down certain axioms connected with ice navigation which, in their opinion, should not, if possible, be departed from. Nansen has set these at defiance, for one of the most important of these rules, connected with the exploration of high latitudes, is to adhere to the coast and to keep away from the pack. Nansen has done exactly the contrary, for he has started with the express intention of keeping away from the land, and forcing his ship into the ice.

Not only was Nansen guided, in forming his ideas, by the well-known drift of ships, and of parties of men who had drifted for many hundreds of miles on ice floes after the destruction or loss of their vessels, but he enforced his arguments by accepting as a fact the reputed discovery of various articles on the southwest coast of Greenland, which were supposed to have been lost from the *Jeannette*, and which, if this supposition is correct, could only have reached the position where they were found by drifting across that point situated on this terrestrial sphere where the northern axis of our globe has its termination. But even, for the sake of argument, admitting that Dr. Nansen's conjecture regarding the oceanic drift of the northern region is correct, the presence of land, and it need only be a small island, directly in his path, would suffice to upset his plans, and put an end to the drift of his vessel in the same way that Wilezek Island put a stop to the further drift of the *Tegetthoff*. My own view regarding the direction of the currents in the Arctic seas is that they have an unmistakable southern tendency, and that this southern drift is caused by the outflow from the polar basin due to the periodical thawing during the summer months of the enormous quantities of snow and ice that accumulates during the long winters in the neighborhood of the North Pole, and which must necessarily seek an outlet to the south.

The last news we have of the expedition is contained in a letter from Dr. Nansen written on board the *Fram* on August 2, 1893. They were then in Yugor Strait, and were all well, happy, and confident of success. Nansen's intention was then to proceed along the Siberian coast until the mouth of the Olenek River to the east of the Lena delta was reached. Thence he proposed steering a northerly course to the west of the New Siberia Islands as far as the open water would let him, and then to push his vessel into the ice to be carried by it in that northerly current in the existence of which he so firmly relies. He concludes his letter by saying, "When years have passed, I hope you will some day get the news that we are all safely returned, and that the knowledge of man has advanced another step northward." Fortune always favors the brave, and let us fervently pray that the little *Fram*

is still intact, and that before long we shall hear of the safety of the plucky and enthusiastic explorer and his gallant companions, and when we do hear, may we rest assured that, even if his theory has proved an unpractical one, he will still have achieved such a measure of geographical success as will reflect credit on himself and on all concerned.

Very interesting information respecting the New Siberia Islands has been culled by Baron Toll, who paid a visit to that little-known group in the spring of 1892. Leaving the mainland on May 1, and accompanied only by one Cossack and three natives, he traveled over the ice in sledges drawn by dogs, and reached the south coast of Lyakhov Island. Here some very interesting discoveries were made. Under what is described as the "perpetual ice" they found not only fragments of willow and the bones of post-Tertiary mammals, but also complete trees of *Alnus fruticosa* 15 feet in length, with leaves and cones adhering, thus proving that during the mammoth period tree vegetation had reached the seventy-fourth degree of latitude three degrees farther north than it is found at the present time. The "perpetual ice," Baron Toll asserts, is not due to the accumulation of snow, but must be considered as originating from the ice during the glacial period, representing, in fact, remains of the old ice cap.

It is a great pity that no account of the state and condition of the ice to the northward of the islands is given by Baron Toll. A knowledge of it would be of the greatest interest at the present time, as enabling us to form some opinion respecting the character of the pack in which we must assume the *Fram* is now imprisoned. His account of the islands, their geological formation, natural history, etc., is extremely interesting, more especially with regard to those great masses of buried ice, in which has been found in incredible quantities the bones and tusks and, indeed, whole skeletons of the mammoth, rhinoceros, and even the musk ox, and in such a wonderful state of preservation that the tusks so found can not be distinguished from the very best and purest ivory.

The cruise of the *Jeannette* in this particular locality did not add very much to our geographical knowledge of the Arctic regions, but this much was accomplished, namely, the penetration, by way of Bering Strait, to a greater distance into the unknown area than had ever been reached in that direction before. The *Jeannette* was, it will be remembered, beset in the ice on September 6, 1879, to the northward of Herald Island, in 71° 35′ north latitude and in 175° west longitude. In this pack she remained helplessly fixed until she was crushed by it in June, 1881. During this long period her drift was somewhat remarkable. During the first twelve months of her imprisonment she drifted about 150 miles in a north-northwest direction, and during the last nine months the current had carried her no less than 250 miles to the northwest. It is also a curious fact that between April 26, 1880, and November 3 of the same year, she was carried about in such an erratic manner,

due probably to strong tidal action, that she was almost in the same position on the last-named date that she occupied in April, notwithstanding the fact that during those six months she was never stationary, always drifting with a greater or less rapidity in one direction or another, sometimes even at the rate of 4 knots an hour. During the entire drift of over 400 miles the *Jeannette* was in a comparatively shallow sea, of a uniform depth of between 30 and 40 fathoms, but occasionally a depth of 70 and even 85 fathoms was recorded, the bottom consisting generally of soft mud. Although Captain De Long ascribed the drift of the ice in which his ship was beset to the prevailing wind, which was from the southeast, I am inclined to think that it was also materially influenced by the water of the Lena River emptying itself in that neighborhood into the Arctic Ocean. The greatest pressure of the ice was invariably experienced at the change of moon, and it was considered that this pressure was in a great measure due to the action of tides. Although the ice was apparently of the same massive character as the so-called palæocrystic sea to the north of Smith Sound, yet one of the greatest inconveniences from which the expedition suffered was caused by the impurity of the ice, which was so salt as to be quite undrinkable, and they were consequently compelled to obtain their fresh water by distillation. One of the results of drinking the water made from this ice was that it produced excessive diarrhea in those who drank it. Dredgings were occasionally obtained during their drift, but the results were comparatively valueless.

The most important geographical work accomplished by this expedition was the discovery of Henrietta, Jeannette, and Bennett islands, which, I think, may be regarded as part and parcel of the New Siberian group. Round the shore of the last-named island a strong tide, estimated at 3 knots an hour, was observed, and the rise and fall of the tide was found to be 2½ feet. Traces of reindeer were seen on the island to the eastward by Captain De Long and his party, and bituminous coal, which burnt readily, was found and actually used by them, on Bennett Island. Glaciers, presumably discharging ones, were also seen on the island.

One of the ships dispatched by the United States Government (the *Rodgers*, under the command of Lieutenant Berry) to search for the missing *Jeannette* made a very complete exploration of Wrangel Island, which must be regarded as a great geographical achievement. This island had long been wrapped in obscurity, if not mystery. Wrangel himself endeavored, but without success, to reach it with dog sledges in 1822 and 1823. Captain Kellett, in the *Herald*, sighted it in 1849, but no one (with the exception of the captain of the *Corwin*, who succeeded in landing on it a fortnight earlier) had ever reached it or fixed its position, except approximately. Thanks to the efforts of Lieutenant Berry, it is now well known, and its position accurately determined. From Wrangel Island Berry pushed to the north, but was eventually

stopped by impenetrable ice in latitude 73° 44″ and in longitude 171° 30″ west. Returning to the southward, he made another attempt further to the westward, viz, on the meridian of 179° 52′, but only succeeded in reaching the latitude of 73° 28′, when he was again stopped by the formidable character of the ice. Berry made tidal observations off Herald Island, and found that the flood tide set to the northwest and the ebb in the opposite direction. At high and low water no current was perceptible.

All reports relative to the nature of the ice north of Bering Strait coincide with regard to its massiveness and impenetrability. De Long was beset in the same heavy ice. Collinson made several efforts to penetrate the pack in various directions, but without success, and he was at length compelled to return to the lead of open water that is invariably found during the summer along the coast of Arctic America. This navigable channel is due to the grounding of the heavy polar pack in the shallow water that extends for a considerable distance off the land. It was in this ice-free channel that Collinson and McClure sailed along the entire American coast to the east, enabling the former to reach the one hundred and fifth meridian of west longitude, thus overlapping Parry's discoveries to the westward by a considerable distance. But both these navigators, skillful and daring as they were, were never able to penetrate what we may fairly designate as the palæocrystic ice, which they met when they attempted to push to the northward beyond the seventy-sixth parallel of latitude.

Collinson states that some of the floes were as much as 30 feet above the water. Taking the ordinary flotation of ice as having seven-eighths immersion, we thus have the thickness of the ice floes established as over 200 feet. This was about the thickness of the ice, as estimated by similar deductions, over which I traveled in 1876 to the north of Smith Sound. Captain McClure encountered the same kind of ice. He describes it as of stupendous thickness and in extensive floes from 7 to 8 miles in length, the surface not flat, but rugged with the accumulated snow, frost, and thaws of centuries. Off the west coast of Banks Land the surface of the oceanic ice floes was of an undulating nature, 100 feet from base to summit, rising in places as high as the lower yards of the *Investigator*. The current experienced along the coast of North America was invariably in a northeast and east-northeast direction. The current in Prince of Wales Strait is attributed by Collinson to wind.

No more important or interesting work associated with north polar research can be conceived than the exploration of that vast unknown region situated between Wrangel Island and Prince Patrick Island, and the connection of Prince Patrick Island with Aldrich's Farthest in Grant Land. But it is a work that can only be accomplished by a regular and systematic process, for all navigators who have approached this rim of the unknown region—Collinson, McClure, Parry, McClintock,

and De Long—all testify to the heavy and formidable character of the ice, and unite in their views regarding the difficulties that must be overcome before success in this direction can be attained.

Casual exploration by single ships, without proper support and without taking the necessary precautions which I think all Arctic authorities are unanimous in advocating, should be deprecated as much as possible. With proper care, and the establishment of depots of provisions and boats in previously arranged positions, no danger need be apprehended to those who form part of an efficiently equipped expedition, dispatched for the exploration of this portion of the Arctic regions.

The next portion of the unknown with which I will deal is that large tract of land called Greenland, and seas adjacent. It is in this direction that the highest latitude has so far been reached, and this has been accomplished solely in consequence of the extension of land in a northerly direction. Although much has been done in this region, much yet remains to be accomplished.

The connection of Cape Bismarck on the east coast with Cape Kane (Lockwood's Farthest) on the north coast is of the greatest importance, as setting at rest the question of the boundaries of Greenland and the determination of its insularity. The amount of coast line to be explored and the distance to be traveled in order to solve this geographical problem is not very great, probably not more than 450 or 500 miles, but of course much time and trouble must be expended in reaching either of the above-mentioned positions before starting on new ground. Civil Engineer R. E. Peary of the United States Navy has shown us what can be done in the way of traveling in the interior of Greenland by an energetic and persevering explorer. He, it will be remembered, established himself during the summer of 1891 in McCormick Bay, in 78° north latitude, at the entrance to Smith Sound. During the following year he traveled across the entire breadth of Greenland, from his headquarters in Murchison Sound to a large bay which he reached on the northeast coast of Greenland, which he named Independence Bay, on about the thirty-fourth meridian of west longitude. During this somewhat remarkable journey the explorers reached an altitude of over 8,000 feet above the sea level. Departing from the usual method of carrying out exploration in the arctic regions, namely, adhering to a coast line, they pushed boldly into the interior, utilizing the inland ice as the roadway on which their sledges were drawn by dogs. It is significant, as illustrating the severe nature of the traveling experienced, that although they started with 25 dogs, only 14 were alive when they reached their most northern position, and only 5 survived the whole journey, the remainder having succumbed to the hardships of the work in dragging the sledge or had been killed in order to supply the party with food. During the outward journey Peary estimated the distance he traveled at about 650 miles, at an average rate of $16\frac{1}{4}$ miles for each

day of sledging. The weather experienced was, on the whole, mild, the lowest temperature recorded being —5° F., although at an altitude of 8,000 feet. The information supplied by Peary relative to his observations in this part of Greenland is extremely interesting. He found, beyond the glaciers and fiords that intersect the west coast of Greenland, large glacial basins extending into the interior to a distance of from 30 to 50 miles. These basins are separated from each other by ranges of hills varying in height from 5,000 to 6,000 feet, and at least 2,000 feet above the basin plateau. Peary states that the north end of the great inland ice cap terminates in about 82° north latitude. He followed its edge some 60 miles along this parallel, and observed it extending in an easterly and westerly direction for a considerable distance. He has established the fact that musk oxen inhabit those dreary regions, and he found excellent pasturage in the sheltered valleys, where some 20 of these animals were observed browsing. From Independence Bay to the position reached by Lockwood in Greeley's expedition is comparatively a short distance. At Peary's most northerly position, at a height of 3,800 feet, he observed land at an estimated distance of about 60 miles in a northeast direction. This land showed no sign of being capped by ice, and is possibly a portion of an archipelago of unknown extent. It is a noteworthy fact that, in addition to the well-known fauna found in high latitudes, two humblebees and several butterflies were seen.

Interesting ethnological observations were made at the winter quarters, and much valuable information relative to glacial geology in that particular locality obtained. Altogether Lieutenant Peary is to be congratulated on the successful result of his exertions.

Although Lieutenant Peary was engaged last year in continuing his researches in North Greenland, he has not, from various unavoidable causes, added much to his previously acquired geographical knowledge of that region; but a journey was made by Mr. Astrup, one of the members of his expedition, round Melville Bay, resulting in some highly interesting observations relative to the glaciology of that part of Greenland, and a more accurate mapping of the coast line in that vicinity. Lieutenant Peary, with praiseworthy persistency, is still engaged in his valuable work of exploration, and I have no doubt in a short time we shall have more interesting and valuable results to chronicle.

While treating of Greenland, we must not omit that large archipelago of islands situated to the west of that great continent, and north of Lancaster and Barrow strait. Here we have a most interesting region, new to the explorer, and which may be regarded as virgin territory. Its edge has been lightly touched by Perry, McClure, and McClintock to the west; by Franklin, Sherard Osborn, and Belcher to the south; by Greeley and Aldrich to the north, and by Kane, Hayes, Hall, and Nares to the east. It is impossible to conceive anything more interesting or

more valuable, in a geographical sense, than the connection of McClintock's discoveries in Prince Patrick Island with Aldrich's farthest along the north coast of Grinnell Land.

There are different routes by which exploration in this direction can be carried out. In the first place, it can be undertaken from Discovery Bay (where H. M. S. *Discovery* wintered in 1875, and which was also the headquarters of the Greely expedition six years later), by proceeding up Archer Fiord until the boundary of the undiscovered region is reached. Secondly, there is the route northward, using Prince Patrick Island or Melville Island as the base of operations; and, lastly, there is the way by Jones Sound. The latter, I am inclined to think, is the route that will yield the greatest amount of success. No one has as yet succeeded in penetrating to any great distance in this direction, but then no serious effort has ever been made to do so. Whalers have occasionally looked in, but, finding it blocked with ice, and therefore inaccessible to whales, have not persevered in pushing on, but have continued their journey to Barrow Strait and Prince Regent Inlet, where whales are known to abound. Sherard Osborn, in the *Pioneer*, ascended the sound for some distance, until stopped by ice. He reports the scenery on either side as magnificent; long winding glaciers pouring down the valleys and projecting into the deep blue waters of the strait. Traces of Eskimo were discovered, but of supposed ancient date, and vegetation, quite as luxuriant as was seen farther to the southward, was found.

It was only last year that Mr. Bryant, in command of the Peary Auxiliary Expedition, endeavored to penetrate into Jones Sound while searching for the missing Swedish naturalists, Messrs. Bjorling and Kalstenius; but he had other important duties to carry out, and, unfortunately, had not the time at his disposal to persevere in his efforts to push northward.

A few words relative to those two gallant Swedish gentlemen, who sacrificed their lives in the cause and in the interest of geographical science, will not, I think, be inappropriate at the present juncture. It will be remembered that they set out in 1892 with the intention of exploring that practically unknown country situated on the northwest side of Baffin Bay, called by Admiral Inglefield Ellesmere Land. Purchasing a small, and I fear somewhat unseaworthy schooner, named the *Ripple*, at a comparatively insignificant cost—for their means were limited—and with a crew of only three men, they sailed from St. John's, Newfoundland, on their adventurous voyage. Godhavn was reached in safety, and they left that port on August 3, since which time nothing has been seen of them, but the wreck of their little craft was found by a whaler the following year on the southeast island of the Cary group. Not far from the wreck was the body of a dead man, buried under a heap of stones. Some letters from Bjorling were also discovered concealed in a cairn adjacent. From the contents of these we gather that

the *Ripple* reached the Cary Islands on August 16, only thirteen days after leaving Godhavn, but was, unfortunately, wrecked the following day while taking on board the provisions deposited there by Captain Nares in 1875. The party remained several weeks on the island, but eventually left in an open boat for Cape Clarence or Cape Faraday, on the west side of Baffin Bay, in the hope of falling in with the Eskimo that were supposed to be in that neighborhood. The date of the letter is October 12, 1892, and a significant statement was made in it to the effect that their provisions would not last beyond January 1. Their numbers were then undiminished, but one man was dying. This is the last news that has been received of these gallant and enthusiastic young explorers. Careful search was made for them in the Cary Islands, at Clarence Head, Cape Faraday, and along the north shore of Northumberland Island, as well as the entrance to Jones Sound, during the summer of 1894, but, alas! with an unsuccessful result, and it seems more than probable that they lost their lives while attempting to cross from the Cary Islands to Cape Clarence, a distance of about 50 miles, in a frail and probably leaky boat.

I will now conclude my address with a brief summary of the results that would accrue by a systematic exploration of the unknown area in the arctic regions.

The most important would, in all probability, be those connected with physical geography and geology. The geology of the far north is known only in fragmentary patches, but even this limited knowledge proves it to be of a varied character. If all these patches were joined and dovetailed together, facts even more remarkable and interesting than any yet known would be revealed. What can be more interesting, from a scientific point of view, than the account of Baron Toll's valuable researches in the New Siberia islands, and the extraordinary Post-Tertiary deposits that he discovered there? Then, again, it must not be forgotten that the north shore of Grinnell Land, and also the coast of that part of North Greenland known as Hall Land, are plentifully bestrewed with erratice ice-born bowlders. Dr. Bessels, the chief of the scientific staff of the *Polaris* expedition, was, I think, the first to recognize that these bowlders had no connection with the rocks in situ; but he came to what I can not help thinking (and in this belief I am supported by Colonel Fielden, who served as naturalist in Nares's expedition) was an erroneous conclusion, viz, that they must have been transported from South Greenland, and consequently at one time the current must have been from the south to the north. It is, in my opinion, far more likely that these erratic bowlders were transported on ice floes from land nearer to the north pole than we are at present acquainted with.

I do not think, but I speak under correction, that the glacial geology of Europe can be properly understood and described without a more thorough knowledge of the great glacial sheets of the north, for we may safely assume that the arctic regions at the present moment are in very

much the same condition as was this country during the Glacial period. Scores of people have expounded their views on the Great Ice age, but how many of them have had any personal acquaintance with those stupendous masses of ice to be found only near the poles? The majority of these writers argue mainly from their experience of the puny glaciers of the temperate zones. It has been gravely asserted, and in a journal of a scientific society, that ice does not wear down rocks, and that the idea of fiords being excavated by glaciers was a theory that is now abandoned by all geologists. The writer holding these astonishing views must allude to those geologists who have never visited the Arctic regions: for all those who have seen for themselves the wonderful results of the movements of huge bodies of ice and the marks of glaciation so frequently seen on the rocks of the north must think differently. These are questions that can only be satisfactorily decided by a continuance of polar explorations.

The science of ethnology would be largely benefited by further investigations in the far north. It may very truly be affirmed that we are only just beginning to know something about the Eskimo from a scientific point of view. It is now recognized as an almost accepted fact that they did not come from Asia, and that the few found on the Asiatic side of Bering Strait migrated from the American side. Rink and other authorities contend that they are essentially of American origin, but the route they took from America is still an open question. A study of the folklore of the Eskimo would doubtless throw new light on the subject. Boas and Rink have shown, and the Danish expedition which, under command of Lieutenant Ryder, recently wintered on the east coast of Greenland, confirmed, that new legends have a most important bearing on the question of the origin and migration of these nomadic tribes. An ethnologist who took the trouble to learn their language, or who had a trustworthy interpreter, could, with the greatest advantage to science, spend a year or two among the Mackenzie River, the Ponds Bay, the Smith Sound, or indeed any other Eskimo race, for, with the exception of a slight and imperfect knowledge of the Labrador, Greenland, and Cumberland Sound people, absolutely nothing has been done in a field of research which promises such a rich and abundant harvest to the cultivator. As Dr. Robert Brown, one of the greatest authorities on this subject, says:

> There are no people on the face of the earth whose characteristics separate them more completely from other races of mankind than the Eskimo. They are extremely homogeneous in physical features, in language, in social habits, in religion, and in modes of life. . . . Though divided into tribes and grouped into broader sections, the Eskimo are everywhere the same people from the eastern point of Siberia to the eastern shores of Greenland.

Their habitat is the habitat of the seal, the walrus, and the polar bear. But the first named animal is everything to the Eskimo; it is his food, it gives him light, warmth, clothing, implements for the chase,

shelter, harness for his dogs, and material for the construction of his boats and canoes. Without the seal the Eskimo would be in a parlous state; with the seal he requires but little else.

Traces of the existence of the Eskimo were found as far north as the eighty-second parallel of latitude on the west side of Smith Sound, by Captain Nares, and this, I think, is the most northern vestige of the existence of human life that has ever been discovered. Further researches in high latitudes may bring to light traces of the wanderings of these tribes still farther north.

With regard to zoology, it must, I suppose, be confessed that the terrestrial animals of the far north are fairly well known, but we have yet much to learn regarding their habits and geographical distribution. There are many land species, such as fresh-water fishes, mollusca, and insects, that we are compelled to acknowledge must lead a peculiar existence, for, as far as we know, they must be frozen during the entire winter. That must also be the fate of the pupæ of butterflies where the soil is frozen to a great depth, and of the inhabitants of fresh-water lakes and pools which in the winter become solid ice. The question is, how do they live? This and other physiological questions, such as those affecting hibernation in extreme cold, have never yet been satisfactorily explained, and can not be investigated except on the spot and by an expert. Moreover, there are myriads of marine animals in the north, such as acelephæ (jelly-fishes), etc., which rise to the surface on the calm summer days; it is important that these should be drawn and examined from actual observation, for this has never yet been done. Soundings, temperature observations, dredgings, and other physical observations even in Davis Strait and Baffin Bay would not only be important from a geographical and geological point of view, but would yield zoological materials of the utmost value to science. And what is said about Davis Strait applies equally to Bering Sea, Hudsons Bay, and the Spitzbergen Sea; a physical and biological survey of these regions would be of the greatest interest and importance.

Then the distribution of some of the Arctic animals is somewhat puzzling. Take, as an illustration, the musk ox. During the Glacial period it lived in Europe, but now it is almost entirely confined to America, to the islands north of that continent, and to Greenland; even in America it inhabits a very limited area bounded on the west by the Mackenzie River. This in itself raises so many questions, geological, geographical, and zoological, regarding the former land communications by way of the Orkney, Shetland, Faröe Islands, and Iceland with the still farther north, and by Greenland with Spitzbergen, that it is impossible to conceive a more instructive monograph than one written on the range of the musk ox.

The botany of the Arctic regions has, I presume, been fairly well investigated, at least, so far as the flowering plants are concerned, but the lichens, algæ (both fresh-water and marine), mosses, and fungi remain imperfectly known. It is, I believe, still a vexed question

among our most eminent botanists as to whether the Arctic flora was originally European or American. There is also an idea that at the beginning of the last Glacial period the Arctic flora was driven south, and, after the return of warmer times, followed the retreating ice, with the exception of those species that were stranded and had taken refuge on the mountain tops, the so-called Alpine flora. Further investigations in order to elucidate and solve these interesting botanical problems would be of the greatest value.

We have yet much to learn respecting the currents of air, the temperatures, and other matters connected with meteorology which, in all probability, will be found, in a great measure, to affect the climate conditions of lower latitudes. Further investigations in this particular branch would doubtless result in the attainment of knowledge that would be of great practical use and importance.

What has been designated as the Greenland föhn is an atmospheric condition prevailing at the same moment over different portions of the Arctic regions situated at wide distances apart, and of which at present little is known. At the *Alert's* winter quarters off the northeast coast of Grinnell Land in 1875, we experienced great fluctuations of temperature, varying no less than 55°; that is to say, that the thermometer would make a sudden and rapid rise from −20° to +35°, and sometimes this unusually high temperature, invariably accompanied by a south wind, would last for a great many days, thus occasioning us serious inconvenience from the unexpected warmth, for which we were entirely unprepared. These warm southerly winds were felt on the west coast of Greenland, between Ivigtut and Upernivik, precisely at the same time that they were experienced by us, thus pointing to the fact that the warm wave must have traveled at a prodigious rate, and from a considerable distance, in order that it should have been felt, practically, at the same time in places so widely separated. De Long also remarks an unusual rise of temperature in the month of October, when he was beset in the ice and drifting to the north of Herald Island, and this increase of temperature was always accompanied by a southeasterly wind. Immediately the wind veered round to the west, or even to the southwest, the temperature promptly fell.

This brings us to the equally important question of oceanology, which should comprise a complete knowledge not only of the surface currents in the Arctic seas, but also surface and deep-sea temperatures, formation, depth and nature of bottom, influence of tides, density of sea water, varying conditions of ice, and other matters connected with the hydrography of those regions. The strongest known currents that have an outlet from the north polar basin are undoubtedly those that flow to the southward down Baffins Bay and Davis Strait and along the east coast of Greenland. These are apparently uninfluenced by wind, and their drift is both regular and rapid throughout the year. The study of the system of these inflowing and outflowing currents is one of great complexity but of vast importance.

Tidal action has been observed in nearly every part of the Arctic regions that has been visited by man, but probably from a want of synchronous observations we have yet much to learn in this respect.

A more complete knowledge of the nature, character, and size of the icebergs and ice fields met in various parts of the polar regions, together with other glacial observations, would also be of exceptional interest.

Nor must we omit from the results that are likely to accrue to science by continued exploration in the Arctic regions those connected with terrestrial magnetism and spectrum analysis, to say nothing of the importance of obtaining pendulum and auroral observations in high latitudes. Each and all of these are matters of the highest consequence and deserving of further investigation, and these investigations can only be carried out by competent observers on the spot.

I trust I have said enough to show the value and importance of further exploration in the ice-clad regions of the north. I have endeavored to show as briefly as is compatible with the importance of the subject our knowledge of the north polar regions up to the threshold that bounds what I may designate the terra incognita of the Northern Hemisphere, and I have also attempted to point out the best means by which successful exploration in the unknown regions can be carried out. I would wish especially to lay stress on the fact that any advance into the undiscovered region must be regarded as a success, quite independent of the attainment of any position in near proximity to the pole. Therefore the route that is likely to lead to the discovery of the greatest extent of the unknown region, whether to the north, east, or west, is the one that should be followed in future exploration. If every nation that is represented at this congress—and I think the whole civilized world is represented—were to unite in their endeavors to dispatch expeditions to explore the hidden mysteries of the polar basin, France taking one section, the United States another, Germany a third, Great Britain, Sweden, Italy, Holland, and Norway others, then I am confident that in a short time that large blank space on our globe having the North Pole as its center will be as well known and as accurately charted as are the other known parts of the world. There is plenty of work to do, and there is plenty of room for every nation in this great and interesting scheme of exploration. The zeal, energy, and enthusiasm of those who have preceded us have already acquired for us a knowledge of vast terrritories that a century ago were as much a sealed book as the north and south polar basins are at the present day. Surely in this enlightened age we ought not to hold back where others in the past have led the way. Let us now in this congress use our utmost efforts to effect the exploration of those million and a half square miles of absolutely unknown region surrounding the northern axis of our globe. If we succeed in procuring the dispatch of even one well-organized expedition we shall be satisfied that this congress, at any rate, has not met in vain.

THE ANIMAL AS A PRIME MOVER.[1]

By R. H. Thurston.

PART I.—THE HUMAN ANIMAL AS A VITAL PRIME MOVER AND A THOUGHT MACHINE; THE ENERGETICS OF THE VITAL MACHINE; ITS TRANSFORMATIONS.

The vital engine, the body of every vertebrate animal—from the human ruler of all, down to the lowest organism having a cartilaginous frame—is to-day well recognized as, in the engineer's classification, a "prime motor," in which the latent forces and energies of a combustible "food," of a fuel, as many suppose it, are evolved, transferred, and transformed to perform the work of the organism itself, to supply heat to keep it at the temperature necessary for the efficient operation of the machine, and for the performance of external work. The value of the machine as a prime mover is dependent upon the relation between this external work, so far as it can be applied to useful purposes as labor, and the costs of its production in fuel or energy supply, and in wear and tear and replacement, precisely as with any other machine of the class, whether the source of power be chemical, thermal, electrical, or vital.

The work of the machine is, however, a very different quality and is vastly different in quantity, useful work being compared with supplied energy, and incidental expenditures from that of any other known motor. In the water wheels and windmills, the office of the motor is simply that of transfer of energy of flowing currents of fluid, of water or of air, and without transformation, to mechanism suitable for giving it useful application. The heat engines develop energy previously "latent," potential, as the modern nomenclature would call it, into the kinetic form of thermal motion, and, by transformation, so far as may be practicable, into the dynamic form, make it available for work. Electro-dynamic machinery similarly makes available by transformation the energy of the electric current, and none of these machines has any other function than that of making useful some one energy previously stored by the operations of nature in such form as to be readily applied to his purposes by the hand of man.

[1] From the Journal of the Franklin Institute, Vol. CXXXIX, Nos. 829 to 831, January, February, and March, 1895.

The vital machine, on the other hand, has purposes and performs offices of essentially different kinds. It must not only transform the latent energies of the supplies received by it into useful external work, but all its work being directed toward the sustenance and preservation of the contained soul, as its principal and always essential purpose, all its operations being automatic or self-directed, all its powers of transformation of energy are demanded for the production, by transformation, presumably, of (1) the vital forces and energies; (2) the physical energies demanded in constructing, rebuilding, and operating the animal frame; (3) the external work required to furnish the body supplies, to protect it from decay or injury, and to minister to the physical wants and ethical requirements of the personality of which it is at once the home and the vehicle.

This curious prime mover is thus an apparatus which, from familiar sources of energy, transfers and transforms, for its own purposes and applications, a variety of energies, performing a variety of work in various realms. The nature and composition of the sources of latent energy, always chemical compounds capable of oxidation, are well known; the character and method of many of the internal as well as of the external expenditures of energy are equally well understood; but there are a variety and considerable number of internal operations, involving transformations of energy, the nature and method of which are entirely beyond observation by any process of experimentation yet devised.

"Food" is taken into the body, enters into solution with the peptic fluids, elaborated from previously supplied nutriment, is absorbed into the circulation, and disappears from our sight and reach; heat, carbon-dioxide, vapor of water, various salts, and a considerable proportion of unutilized nutriment are rejected from the system, and work is performed as the product of transformed energies and in large amount, both within the machine and upon external bodies. A chain of energy transformations is in continuous operation, of which we see the two ends, so far as the vital machine is concerned, but of which we only get occasional glimpses between the extremities, and some of the links of which are, as yet, undiscovered and unknown. It is certain that the series of changes, material and kinetic, involves familiar methods of transformation, and it is hardly less certain that singular and probably wonderful and unknown processes of energy development and transformation are concealed within this miracle among machines.

Possibly a study of the present state of scientific research relative to this machine may give at least some idea of the importance and complexity of the problems here placed before the man of science and the engineer, if not give a clew to their final solution.

The source of power in the animal machine is invariably the stored chemical energy of vegetation, the potential energy of the hydrocarbons and other compounds contained in all plants, and capable of uniting

with oxygen to form carbonic acid, water, and salts capable of solution in water. It is possible, but perhaps not probable, that other substances and energies forming constituents of these compounds may exist, having eluded the investigating chemist and physicist; but this is thought unlikely. We probably know precisely what enters the animal prime motor, and what are the sources of all its energies. Food and air are the two known elements of all its powers. It is also possible, but probably not the fact, that this machine may drink in from the surrounding ether some portion of its energy in forms still undetected and unsuspected. We are compelled, for the present, certainly, to assume that all the energies developed and applied in the vital machine are initially latent in vegetable matter, air, and water. This organic substance is derived by the carnivorous animals indirectly through the other creatures, all of which live upon vegetation directly. The organic forces of plant life derive all energy from the inorganic world of minerals and from the gases of the atmosphere by utilizing the primary energy of solar rays in the chlorophyll with which every leaf is provided, as the active agent in that transformation. The vital machine thus ultimately derives all its energies from the sun.

Food is the material in which are stored the substances supplied to the vital machine as the reservoir of the potential energy from which the required energies, in various active forms, may be derived, as demanded, to perform the work of the body and the mind. It consists of a mixture of edible and other matter, the former being that part from which energy is derivable: the latter being indigestible and unassimilable and only useful in promoting, by mechanical irritation, the action of the digestive system.

All foods contain:

Water—required for solution of nutrients.

Nutrients—protein, fats, carbohydrates.

Innutrient matter.

Protein consists of the albuminoids, and, in vegetable matter, the amides, a less valuable portion of the food. The white of egg, the fibrine of meat, and the gluten of wheat are illustrations of albuminoid compositions.

Fats, such as those of meat, and the greases of vegetation, the oils of the animal and vegetable compounds extractable by ether constitute the basis of construction of the fats of the body and of a part of the nerve and brain substance.

Carbohydrates are the starches and sugars of the vegetable.

Salts are found in both animal and vegetable foods, and are in some cases essential elements of the compositions making up the body, though not, in the ordinary sense, digestible and nutrient.

Mineral matters constitute, in the case of the vegetable foods, the principal portion of the innutrient matter of food, and form the ash when the plant is burned. In some cases these mineral matters serve

as stimulants of digestive and other physiological processes, even when not themselves in any degree digestible, and are, for that reason, essential constituents of food. It is for this reason largely that vegetable foods are indispensable to perfect action of the functions and to bodily and mental health. The vegetable food also, especially the fruits and grains, contain the required elements of all the compositions of the animal system in best proportion and best arranged for utilization by man and all other except the purely carnivorous animals. Could the whole animal be used as food, including blood and nerve and bone and brain, animal food would be substantially correct in composition: but it would still lack the stimulating property of the other class of foods which comes of the presence of the mineral and indigestible elements.

The uses of food are mainly two: (1) To supply material for the building up and the repair and maintenance of the tissues of the body. (2) To furnish the energies required in the operation of the animal machine in their various forms and in due proportion.

The first is the direct application of a portion of the food. The second disposition of the elements of the food and their potential energy may be direct, as probably in the use of the fats, the combustion of which to carbon-dioxide and water results in the production of immediately available energy; or it may be indirect, as where the carbohydrates are first digested and, later, consumed in similar manner to the fats; or, still more indirectly, as where the protein becomes first a part of the flesh or of the nervous system and, later, broken down in the course of the work of the body, serves as fuel or otherwise in the production of heat or other energy by its oxidation.

Protein forms tissue—muscular, nervous, and other. Fats form a part of the nervous tissue, and carbohydrates are converted by the digestive organs into fats, and then serve the same purposes. Both the latter compounds serve as fuel or energy storing reservoirs, contain a quantity of potential energy, which is sooner or later drawn upon in the development of the various energies utilized in the operations of the body and the brain. It is usually assumed that the energy demanded is that of thermal molecular motion, and that the value of the foods may be measured by their calorific content or potential thermal energy. Until it is known just what energies are employed in the numerous and varied operations of the living creature, and to what extent they are severally derivable from the potential energy of the various foods and transformable from one into another, and especially from or into thermal energy, no better method can be devised than that which assumes the value of foods properly compounded in imitation of nature's known proportions—as in milk for children, fruit of palatable character, and grains for adults—to be proportional to their calorific measure. Pure carbon or the pure carbohydrates, however, are not foods in a proper sense, as they could not be converted into muscle, nerve, or bone, and only serve in themselves for energy storage for use by a body composed of protein

largely, and of other essential matter in less proportion. On the other hand, the muscle and nerve and bone-making constituents alone serve to build up the machine, but not to operate it. Ultimately, however, it is supposed that the stored energy of the latter class of compositions become available, and thus both, the original proportions being correct, may have a kind of measure of value in that of their fuel constituents. For highest efficiency, the proportions of the constituents must be suitable for the individual case, and availability by digestion and assimilation, and in the provocation of all essential vital processes, is quite as essential as either of the other required qualities of the food.

The protein compounds are all nitrogenous, whether in the form of albumen, fibrin, casein, or gluten. These compounds are fairly uniform in value. The carbohydrates differ greatly among themselves in this respect. The fats are substantially of equal value as measured by thermal contents, but differ in palatableness and digestibility, and thus in food value. Neither the carbohydrates nor the fats contain nitrogen, and they are simply useful in furnishing a supply of heat or other energy. One unit weight of carbon and one of protein yield substantially equal quantities of energy—about 14,500 British thermal units, or 1,860 calories per unit weight. Its energy is sufficient to raise 2,850 tons one foot high. The same weight of carbohydrate has usually very nearly the same force value. A similar weight of fat should have 50 per cent more stored energy—about 4,700 foot-tons. A pound of corn meal should supply a quantity of energy equal to two-thirds that of an equal weight of carbon—about 2,080 foot-tons, 1,360 calories.

The food consumed daily by a powerful workingman contains, on the average, about 3½ ounces of protein, 6 ounces of fat, and 14 ounces of carbohydrates, according to Professor Woods. Its energy measures sensibly the same as that of 2½ pounds of corn meal. Its protein and fats come largely from the flesh food contained in the daily ration. The carbohydrates come entirely from the vegetable constituents. Another illustrative example of a ration given by the same authority measures 3.8 ounces of protein, 5 ounces of fat, 15 ounces of carbohydrates. The energy stored in the food thus taken measured 5,400 foot-tons, or 3,530 calories. A standard ration for swine contains about 7,500 foot-tons, 4,900 calories, per 100 pounds weight. That for cows measures 4,600 foot-tons, 3,000 calories, approximately, per 100 pounds weight. The ration for sheep measures 5,900 foot-tons and 3,550 calories per 100 pounds.

Food-energy transformation is the office of the vital machine. The fish can traverse the water all day; the bird can fly through the air all day; man and the animals on land can walk all day; and it is evident that, as suggested by Pettigrew, their tasks must be not very far different in magnitude. All exert powers approximately proportional to the volume of the seasoned working muscles employed in these tasks, which, according to various authors, is not far from about the equivalent in

work of one atmosphere, 15 pounds per square inch of section of fiber, rising to somewhat higher figures; but all are very moderate intensities as compared with those adopted in machinery and in proportion to weights developing them. None can therefore find in peculiar tenacities or intensities of action of working parts a means of attaining remarkable power, even in the case of the bird, which was formerly supposed to enormously excel all other creatures in its concentration of power in mass and muscle. We seem thus reduced to the study of the methods of transformation of energy of the foods. The fact that venous blood is warmer than arterial, though very slightly, is another evidence that the transformations of matter, as well as of energy, in these processes occur in the muscular system; and the path into which investigation must be turned would seem to be fairly well located.

Dr. Carpenter was, perhaps, the first to elaborate fully and clearly the idea that the germ of the organism is not the concentrated essence and energy of the organism and all its progeny, but that it is rather constituted as "a directive agency, thus rather representing the control exercised by the superintendent builder, who is charged with the working out of the design of the architect, than the bodily force of the workmen who labor under his guidance in the construction of the fabric." The actual constructive force, he thinks—as we now can see, very possibly, wrongly—is heat.[1]

It may now be taken as certain that, as Dr. Carpenter asserted in 1850, "in some way or other fresh organizing force is constantly being supplied from without" during the whole period of activity of the vital machine, which continues by inheritance to transmit the power of absorption and transformation and of direction of this absorbed energy, for all its various purposes, throughout the life of the whole line of its posterity and that of the race.

Liebig, Carpenter, Grove, and others have long ago prepared the way for the acceptance of the proposition that the organs of the animal which elaborate its powers constitute an apparatus fitted to simply divert the energy received as latent in the food and awakened by the chemical processes constituting digestion, assimilation, and nutrition, and to direct it into its new channels in the form of heat, mechanical energy, and vital power. Sir Benjamin Brodie found that the act of respiration simply did not sustain the temperature of the body, and that the action of the spinal column was essential to the normal development of heat. Helmholtz found the chemical changes greater in muscle in use than when at rest, and a larger proportion of waste, due to

[1] "Thus in the case of the successive viviparous broods of the *Aphides* a germ force capable of organizing a mass of living structures which would amount (it has been calculated) in the tenth brood to the bulk of 500,000,000 of stout men must have been shut up in a single individual weighing perhaps the one one-thousandth of a grain, from which the first brood was evolved," if the theory was true; and "the bodies of all men who have lived from the time of Adam to the present day must have been concentrated in the body of their common ancestor."

the breakdown of tissue, to be produced. Beclard found the quantity of heat developed by voluntary muscular contraction greater when simply an effort is produced, as when grasping an object firmly, than when doing work, as by lifting the object. Matteucci found that muscles absorb oxygen and throw off carbon-dioxide when doing work, and in larger amount as more work is performed.

Dr. Flint, after a very beautiful investigation of the conditions of the muscular system and the changes of tissue in the case of the pedestrian Weston after a five-days' walk, as well as throughout equal periods during and before the tremendous effort which carried him over 117.5 miles at the mean rate of over 4 miles per hour of actual travel, concluded that "work is always attended with destruction of muscular substance;" "the direct source of muscular power is to be looked for in the muscle itself." He thinks that the muscular tissue "can not be absolutely stationary, and disassimilation must go on to a certain extent even if no work is done. This loss must be repaired by food to maintain life." That this is ordinarily, or at least may be, a very small proportion of the energy effect is evident from the well-known conditions of hibernation and by the fact that Dr. Tanner and others have fasted for 40 days and more with no great apparent loss of vital and essential strength, and seemingly at only the cost of accumulated fat disposed of as a superfluity, previously, in the spaces between the muscles. In the case of severe labor, as where a pedestrian continually exerted all his powers for days together, Flint has proven clearly that large quantities of muscular tissue are broken down.[1]

The proportion of nitrogenized or muscle-making food to nonnitrogenized, in the walk here referred to, was, as measured in units of energy, about as 5,700,000 foot-pounds to 39,000,000, or about 15 per cent; which figure will be recognized later as corroborated by other and independent methods of examination of this subject. The total absorbed energy would thus be about 11,000,000 foot-pounds per day, plus that derived by the breaking down of tissue to the extent of the total value of about 3,500,000 foot-pounds, 700,000 per day; that is to say, 11,700,000 foot-pounds of energy were supplied the system per day, when doing an extraordinarily large amount of work, both externally and internally.[2] But Weston is a small man, and probably 10 per cent should be added to make these figures comparable with those elsewhere given as the average for a workingman, 10,000,000 foot-pounds. This gives a total of over 12,000,000 foot-pounds, or 20 per cent above the estimated figure to be later computed for the average regular day's work. The food taken averaged about 20 ounces, a pound and a quarter, but was somewhat concentrated, and stimulating in more than ordinary degree.

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[1] The source of muscular power. New York: D. Appleton & Co. 1878.

[2] The vital machine consists of about 40 per cent muscle, of which a half is water, 12.5 per cent blood, 2 per cent brain, and the remainder is skeleton and internal organs.

As remarked by Professor Foster,[1] "from many considerations it is extremely probable that a chemical change—an explosive decomposition of more complex into more simple substances—is the basis of a nervous impulse." The energy thus developed is largely in this case employed in conveying the impulse along the nerve and in setting up muscular or mental evolutions and applications of energy at its extremity.

The introduction of chemical actions in the production of solution of the available constituents of the food is one of the essential elements of the extraordinarily perfect utilization of all its substance, of its complete digestion, entire absorption, and thorough assimilation. Only from a state of solution could complete absorption or precipitation take place. Food undergoes "profound disruption" before it can become a part of the body or furnish it energy. "It would almost seem that the qualities of each particle of living protoplasm were of such an individual character that it had to be built up afresh from almost the very beginning."[2]

The presence of considerable quantities of phosphorus, especially in the nervous system of the animal, indicates that chemical actions may be very rapid, and possibly may especially indicate the resultant production of peculiar material and nonmaterial output, as the electric current of the gymnotus, if not all animals, light in the firefly, the vital forces of all vital machines. The presence of water in large quantity points the same way.

The blood is the carrier and distributor of all potential energy from the dissolved material of supply, and the capacity of the blood vessels is probably something of a gauge of the quantity of energy supplied the parts to which they lead, and of the mean rate of expenditure during their period of operation and restoration to normal condition of rest. Whether the nutriment and the potential energy thus conveyed supply energy directly, as supposed by Dr. Pavy and others,[3] or indirectly by the upbuilding of tissue later broken down and supplying directly the stock of energy needed for transformation, as supposed and probably experimentally proven by Dr. Flint,[4] the result is the same.

The influence of the form in which the potential energy is supplied the machine is well exhibited where, as in penal institutions like that of the State of New York, "experimental classes can be formed and the effect of the changes thus found practicable observed and measured." The inverse ratio of food supply to crime and to illness had long been recognized by students in anthropology and sociology; the fact that every variation of the quality of an ample food supply produces

[1] Encyclopædia Britannica. Article, Physiology, p. 21.
[2] Ibid.
[3] The Lancet, Nov. 25, 1876.
[4] Journal of Anatomy and Physiology, Oct., 1877.

an effect upon our moods, our powers, and our ability to perform mental even more than manual work is a daily observation with every one; and the suggestion has even been made that the selection of nutriments may be made to produce effects of economic importance in both directions—in making the human as well as the lower order of machine better as a motor, better as an intelligent worker, and even better as a thinker and as a moral creature, which lines of improvement are all essential to further progress in either direction. So far as both experiment and general observation have gone, at present, it may safely be stated there can be no question that the value, the power, the efficiency and durability of the mechanical and of the mental side of the vital apparatus are both influenced essentially by the nature of the material selected as the reservoir of potential energy, to be rendered kinetic and to be applied to useful purposes by it.

As indicated by Dr. Carpenter, in the middle of the nineteenth century, it would seem now certain that "motor force may be developed, like heat, by the metamorphosis of constituents of food which are not converted into living tissue;" while there is also no doubt that, in many cases at least, the disintegration of tissue which has completed its period of service in the organism may, precisely as does the digestion of animal food, perform its part in the supply of potential energy to the system for utilization in vital and other operations. As the same great physicist and physiologist has stated it:

The life of man or of any of the higher animals consists essentially in the manifestation of forces of various kinds, of which the organism is the instrument, and these forces are developed by the retrograde metamorphosis of the organic compounds generated by the instrumentality of plants.

Thus, during the whole life of the animal, the organism is restoring to the world around both the materials and the forces which it draws from it; and after its death this restoration is completed, as in plants, by the final decomposition of its substance.

As was, perhaps, first stated explicitly, by Liebig, we find that the sources of all forces, powers, energies, in man and animals, are to be found in the food constructed by the plants out of mineral substances under the active energy of the sun's rays, which energy, becoming thus latent, is reawakened by the vital apparatus and directed into useful channels, constructing the whole animal machine, and doing all its work—muscular, thermal, electrical, vital, mental.

The quantity of energy imported into the vital machine, is, in any individual case, readily measurable. It differs greatly with the species, size, temperament and work, external and internal, of the animal, and very greatly with the efficiency of its apparatus of digestion and assimilation. While, for example, one man will live and enjoy life and do his full share of work on 1 pound of good food per day, another will often require 2 pounds or more; and, in some instances, in which disease had reduced the assimilative powers, as much as 7 pounds have

been demanded and still proved insufficient to supply the needed total energy of the system. For a healthy and hard-working man, Dr. Pavy gives 2 pounds of bread and 0.75 pound of meat as a fair ration for a day.[1] Moleschott gives a total of 46 ounces or about 23 ounces in a dry state, and 60 to 80 ounces of water in twenty-four hours. Voit gives 500 to 800 grams, or about 17 to 27 ounces of nutrient matter in the food taken;[2] and, on the same basis, eliminating wastes, the principal investigators give about 550 grams, nearly 20 ounces, as an average. Edward Atkinson gives from 2 to 2.75 pounds per day of common foods as dietaries on which life can be sustained and ordinary work done without strain; but he allows 4 pounds for what may be termed "good living."[3] Much of the food included in the bill of fare of the well-to-do citizen has no real value in nutrition; some of it is actually and often seriously detrimental, and some, possibly a large proportion, is simply superfluity and waste.

The food of a working man contains about 15 per cent nitrogenous matter; that of a young child 20 per cent. Milk contains 25 per cent, uncombined water, as in the preceding cases, eliminated. Eighty-five per cent of the food of the man is thus applicable to work, and 15 per cent to muscle making. Three-fourths of the child's food is suitable for work and production of fat; one-fourth for making muscle. An egg contains 11 per cent fat, 17.6 per cent albumen, and 1.5 mineral matter; or dry, 37 per cent fat, 58 per cent albumen, and 5 per cent minerals; i. e., apparently nitrogenous matter constituted about 0.6 the total weight of the body. A large fraction of the food is thus required for work and heat, a small proportion for building up the machine, or for its repair.

Wheat is usually considered the most perfectly compounded of the grains adapted for the food of man. It contains, according to Scammel, 14.6 per cent muscle-making elements, 66.4 per cent heat-producing material, 1.6 per cent nerve and brain food, and 17.4 water and waste. Oatmeal contains, respectively, 17, 50.8, 3 and 30.5 per cent of these elements. The meats contain 20, 14.2 and 64 per cent. Fish require little heat, obviously, and as food contain 20 per cent muscle-making material, 1 per cent fat, 5 per cent brain and nerve food, and 74 per cent water and waste. Oysters contain two-thirds as much solid matter of substantially the same composition. On the whole, 4 times as much energy is supplied in good food for heat and work as for muscle repair and 40 times as much as for brain and nerve.

Frankland finds the energy per pound of common foods to range from 2,000 or 3,000 British thermal units in the case of the lean meats, to about 7,000 with the grains and their flours, and to over 15,000 in the case of the solid fats. The underground vegetables, which can hardly be

[1] Treatise on Foods.

[2] Mott's Manual.

[3] Thurston's "Animal as a prime mover," page 76.

called foods, such as potatoes, carrots and turnips, contain three-fourths to seven-eighths their weight water, and only supply from 800 to 1.800 British thermal units of energy. In foot-pounds of dynamic power, the figures are 600,000 to 1,400,000 for the last-mentioned substances, 1,500.000 or 2,300,000 for the lean meats, 5,000,000 to 6,000,000 for the grain foods, and 12,000,000 for the fats per pound of nutriment digested. This comparison, however, gives no clew to their value as foods and as nutriment of the vital machine, since it is known that the heat-producing value is but a part of the question, and that the power of assimilating the elements of the body and of producing muscle, nerve, brain and bone is no less essential to the maintenance of the efficiency of the machine than the production of thermal or other equivalent energies. The grains have double the value of the meats as brain and nerve foods, and the coarse vegetables one-fourth the value of the grains in this respect. Butter and lard. the best heat producers, have no value at all as muscle and nerve material.[1]

Voit and others give the correct proportion of these elements in good food as about 120 grams protein, 50 grams of fats, 550 grams of carbohydrates, a total of say, 700 grams, about 23 ounces per day, as the requirement of a man doing a day's work at muscular labor. This provides not far from 3,000 calories of thermal energy by oxidation. Voit gives a total required energy in thermal units of from 3,000 to 3,300 calories, Playfair from 3,000 to 3,700, and Atwater from 2,820 to 4,060 calories; or, collecting all the best authorities, we may say that 3,000 calories, about 12,000 British thermal units, may be taken as representative of the demand of the machine for energy when doing little external work, and 4,000 calories, about 16,000 British thermal units, when performing a hard day's work every day. This means the equivalent of 1 pound of ordinary coal for the first, and an equal weight of the best coal for the second case, burned completely and with, consequently, maximum production of thermal energy and dynamic power. One pound of fairly good coal, say, about 13,000 British thermal units of energy, may be assumed as ample for the production of all the work and power, and all the active phenomena, internal as well as external, of the human machine, when doing a full day's work.

This is 10,000,000 foot-pounds, nearly, of energy supplied.

So far as now known, this food supply and the oxygen required for its complete combustion, with some nitrogen and a minute quantity of mineral matter, constitute the total intake of the animal machine, except that a quart of water, more or less, is needed to dilute the circulating fluids of the system. The next question for our examination is: What amounts of energy are expended and utilized in the various processes of the operation, of maintenance and repair, and of performance of external work, useful and useless, in an average day, with its usual distribution of working time and rest?

[1] Scammel. *Ibid.*, page 74.

The efficiency of the animal, considered as a machine, is now well understood to be dependent, in a large measure, for any given individual, upon the character of the material in which the stored energy supplied it is presented. It is coming to be understood, also, that the same is true of the vital prime mover, considered as a thought producer. It is well known, also, that this is an important element in the maintenance of that ideal state, "perfect health," to which we may approximate, but never absolutely reach, and the approximation to which measures approximation to maximum efficiency under otherwise most favorable possible conditions. From this point of view it is interesting to study the following summary of the distribution of nutritive and of heat-producing elements in the best dietaries, according to accepted authorities, that have been yet proposed. The nutrients, the nitrogenous matters, are classed as including the muscle of meats, the casein of milk, the gluten of grains; while the fats and carbohydrates are taken as purely heat producing, and the following diagram and tables, from the report of 1893 of the Elmira Reformatory, gives the best condensed view of the data required that the writer has yet seen.[1]

The standard dietary for man is usually given as not far from a weight of 700 grams, of which about 60 per cent is generally starchy food, 20 per cent fats, and the remainder nitrogenous: the potential energy stored is about 3,650 calories.[2] But while the actual dietaries are commonly largely composed of animal food, it should be at all times remembered that the teachings of comparative anatomy and of general experience, so far as careful observation informs us, indicate that the vegetable starches and fats and proteins are more suitable for the animal prime motor, and even still more to the thought machine than the carnivorous foods.[3]

It will be noted that the lower limit of supply ranges close upon 400 grams, 2,000 calories, 8,000 British thermal units for little or no labor; that is not far from 600 grams, 3,000 calories, 12,000 British thermal units for the workingman; while double these figures may be reached.

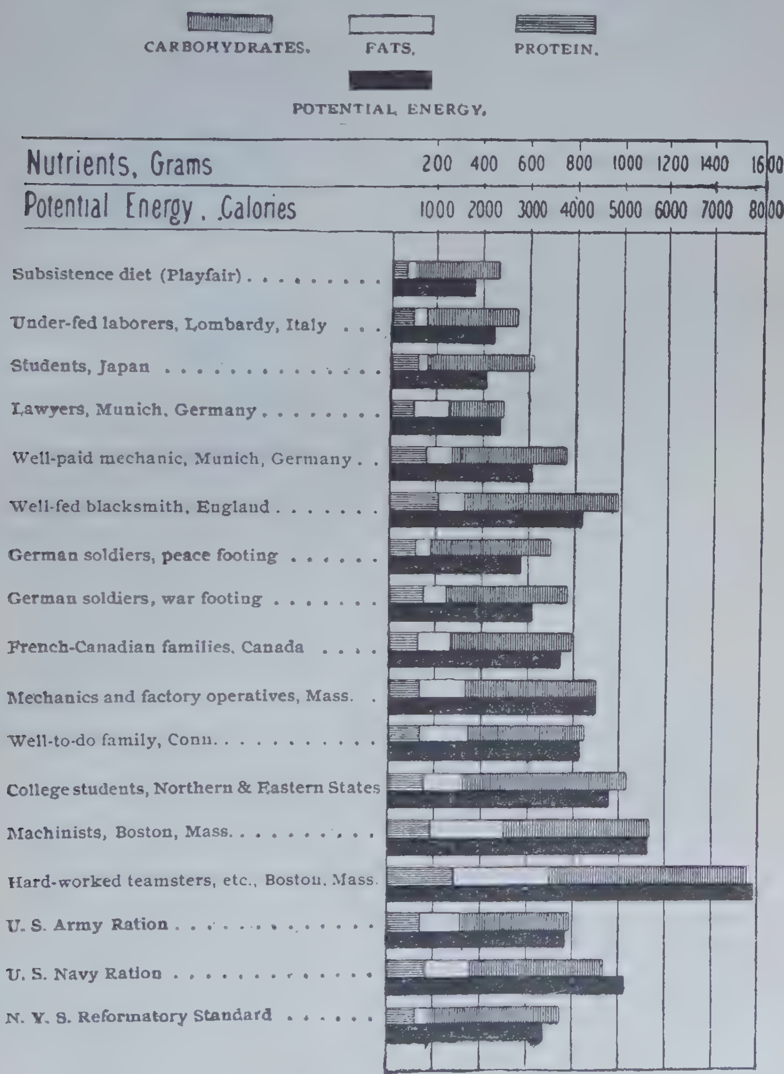
[1] The Eighteenth Yearbook of the New York State Reformatory, at Elmira, issued, under the supervision of its distinguished and successful superintendent, as wholly the product of the talent of its officers and of the manual skill and the taste of its inmates, contains exceedingly valuable and interesting accounts of the manual training system and trade schools there so fruitfully operated.

[2] For present purposes it will be sufficiently accurate to take the gram as one-thirtieth of an ounce and the calorie as four British thermal units.

[3] See particularly, Schlickenysen; "Fruit and bread: a scientific diet;" Holbrook's translation, 1877. See also various papers of The Anthropological Institute of Great Britain, as that of C. O. Groom, Napier, and the address of Dr. Denis at the International Congress of Anthropology, of 1892; which papers and various researches now becoming familiar, show the influence of the character of the energy-storing material supplied the vital engine upon its power and efficiency in both fields of application of kinetic energy derived from the original store of potential.

On account of unavoidable waste, exact standards can not be adopted in a practical ideal dietary, and it is universally deemed necessary to establish, beside an exact standard, an actual practical standard dietary, with somewhat increased allowance. The first table furnishes a comparison of certain daily dietaries computed principally by Prof.

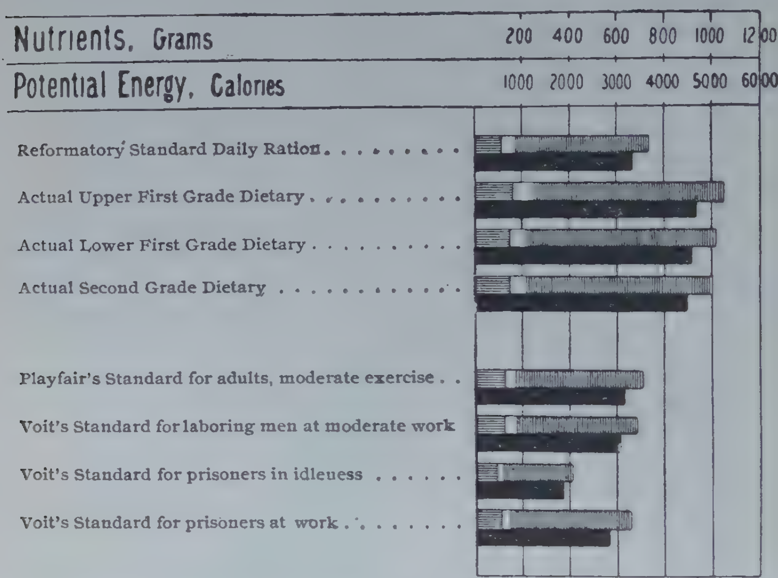
I.—STANDARD AND ACTUAL DIETARIES.



W. O. Atwater, and bearing upon people in various parts of the globe—together with lines indicating the theoretical standard dietary adopted in the Reformatory. The second table offers a comparison between this exact standard and the actual dietary as provided in three grades

established at Elmira, and in contrast, other standards established by Playfair and Voit for adults in general, and for inmates of penal institutions.

II.—IDEAL AND ACTUAL PENAL DIETARIES.



Exact figures corresponding to these lines are presented herewith:

III.—ANALYSES OF ENERGY STORAGE.

	Nutrients, in grams.			Potential energy in calories.
	Protein.	Fats.	Carbo-hydrates.	
Refractory standard dietary daily ration [1]	119	61	556	3,334
Actual upper first-grade ration	167	75	810	4,696
Actual lower first-grade ration	154	69	794	4,524
Actual second-grade ration	154	69	776	4,452
Playfair's standard for adults, moderate exercise	119	51	531	3,140
Voit's standard for laboring men at moderate work	118	56	500	3,050
Voit's standard for prisoners in idleness	85	30	300	1,857
Voit's standard for prisoners at work	105	40	500	2 852

[1] All food supplies are issued according to this standard dietary, *except bread;* which is unlimited. The average consumption of bread per man is somewhat in excess of one and one-half rations per meal, thus accounting for the increase in value of the actual ration over that of the standard dietary, which conforms very nearly in food values to the standards of Voit and Playfair.

An excess above 600 grams, 3,000 calories, 12,000 British thermal units, may probably be taken as representing waste in most cases; it is certainly exceptional. Deficiency is as probably indicated where the weight is less than two-thirds this figure.

The quantity of energy supplied, where the method and material of

supply are suitable, may thus range between 8,000 and 12,000 British thermal units, from 6,700,000 to 10,000,000 foot-pounds per day.

New York State Reformatory dietary.

	Standard daily dietary (in ounces).																					
	Sunday.			Monday.			Tuesday.			Wednesday.			Thursday.			Friday.			Saturday.			Weekly total.
	B.	D.	S.	B.	D.	S.	B.	D.	S.	B.	D.	S.	B.	D.	S.	B.	D.	S.	B.	D.	S.	
Canned corned beef	1.6						1.6						1.6			1.6						6.40
Beef					12			6									6			8		32
Mutton											8											8
Pork (fat)														1								1
Kopf's pea soup		2																				2
Bread	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	168
Potatoes	6				12		6	4		6	4		6			6			6	4		60
Onions								½		½	½								½	½		2.50
Turnips								1			2									2		5
Carrots								1			1½									1½		4
Parsnips								1			1½									1½		4
Beets								½			½									½		1.50
Tomatoes																	2½					2.50
Flour					½						1½						1½			1½		5
Oatmeal[1]								¼														.25
Beans				4				½						6								10.50
Barley								¼														.25
Rice								¾									1					1.75
Molasses																						31
Total, one week																						344.65
Total, one day																						49.24
Bread[2]																						98
Total, one week																						442.65
Total, one day																						63.24
ADDITIONAL FOR UPPER AND LOWER FIRST GRADES.																						
Coffee	¼			¼	¼		¼			¼	¼		¼	¼		¼			¼	¼		2.75
Tea			⅛			⅛			⅛			⅛			⅛			⅛			⅛	.88
Sugar	¼		¼	¼	¼	¼	¼		¼	¼	¼	¼	¼	¼	¼	¼		¼	¼	¼	¼	4.50
Total, one week																						450.78
Total, one day																						64.40
ADDITIONAL, UPPER FIRST GRADE.																						
Coffee		0.2						0.2									0.2					0.60
Sugar		.2	⅜			⅜		.2	⅜			⅜			⅜		.2	⅜			⅜	3.23
Dried apples			⅝						⅝						⅝						⅝	2.50
Currants						¾						¾						¾				2.25
Butter			⅜									⅜						⅜				1.13
Cheese						2			2						2						2	8.00
Total, one week																						468.49
Total, one day																						66.92

B—Breakfast. **D**—Dinner. **S**—Supper.

[1] The writter has, as a matter of experiment, lived for long periods of time on about 12 ounces per day of oatmeal (dry) or the equivalent in "cracked wheat" or other grain, supplying but about 1,400 calories per day, and, leading sedentary life, found this allowance ample. This is also the least costly of all foods, and the writer has known young men to live on 60 cents a week, making up the dietary of grain foods mainly.

[2] Actual average consumption per man per week in excess of standard ration.

New York State Reformatory dietary—Continued.

	Table of food values.									
	Refuse, bones, skin, etc.	Water.	Nutrients. Protein.		Fats.		Carbohydrates.		Mineral matter.	Potential energy.
	Per cent.	Per cent.	Per cent.	Ounces.	Per cent.	Ounces.	Per cent.	Ounces.	Per cent.	Calories.
Canned corned beef		62	30	1.92	8	0.51				358
Beef	19.7	44	13.8	4.41	21.7	7.94			0.8	2.608
Mutton	20	42.9	37.1	2.97	23.2	1.86			.7	834
Pork (fat)	10.4	9.5	2.8	.03	76.5	.76			.8	205
Kopf's pea soup			21	.42	17	.34	46	0.92		246
Bread		32.7	8.9	14.95	1.9	3.19	55.5	93.24	1	13.417
Potatoes	10	68	1.8	1.08	.2	.12	19.1	11.46	.9	1,489
Onions Turnips Carrots Parsnips Beets Tomatoes	10	81	2	.39	.2	.4	6	1.17	.8	192
Flour		4.6	11.1	.55	1.1	.05	75.6	3.78	.6	518
Oatmeal		7.7	15.1	.04	7.1	.02	68.1	.17	2	29
Beans		13.7	23.2	2.44	2.1	.22	57.4	6.02	3.6	1,042
Barley		18	10.5	.03	2.5	.01	67	.17	2	24
Rice		12.4	7.4	.13	.4	.01	79.4	1.39	.4	178
Molasses							63	18.90		2,197
Total, one week				29.35		15.07		137.22		23,337
Total, one day				4.19		2.15		19.60		3,334
Standard daily ration, grams				119		61		556		
Bread[1]				8.72		1.86		54.39		7,827
Total, one week				38.08		16.93		191.61		31,164
Total, one day				5.44		2.42		27.37		4,452
Actual second-grade daily ration, grams				154		69		776		
ADDITIONAL FOR UPPER AND LOWER FIRST GRADE.										
Sugar		2.2	0.3	0.01			96.7	4.35	0.08	507
Total, one week				38.09		16.93		195.96		31,671
Total, one day				5.44		2.42		27.99		4,524
Actual lower first grade daily ration, grams				154		69		794		
ADDITIONAL, UPPER FIRST GRADE.										
Sugar		2.2	0.3	0.01			96.7	3.12	0.8	363
Butter		10	1	.01	85	0.96	.5	.01	3.5	254
Cheese		41.3	38.4	3.07	6.8	.54	8.9	.71	4.5	583
Total, one week				41.18		18.43		199.80		32,871
Total, one day				5.88		2.63		28.56		4,696
Actual upper first grade daily ration, grams				167		75		810		

[1] Actual average consumption per man per week in excess of standard ration.

PART II.—ENERGY SUPPLIED; POWER AND EFFICIENCY; INTERNAL WORK OF THE VITAL MACHINE.

The energy expended by the vital machine consists of:

(1) The external work performed, as the task of the workingman.

(2) The external work performed incidentally outside of that useful work, as in the movements of the limbs, walking, handling the food, and various voluntary and other motions, which constitute a considerable fraction of the more or less necessary expenditure of energy in ways not included in the daily specified task.

(3) The internal work of digestion, assimilation, nutrition, and rejection of excreta.

(4) The internal work of respiration.

(5) The internal work of circulation of the blood and the other fluids of the system.

(6) The internal work of growth, maintenance, reconstruction, and repair.

(7) The internal work of the automatic system regulating the functions and movements of the various organs, both external and internal.

(8) The internal work of conscious direction of the movements of body and limbs, and, in some cases, of internal organs, and, to some extent, of the work of respiration and of circulation.

(9) The internal work of the brain, and possibly of other organs, in the performance of conscious thought and of brain work, a large part of which is essential to the proper performance of the useful work of the vital prime motor, and in the case of the man whose duties are those, distinctively, of the thinker, a large part of which must be rated as useful and prescribed work, determining the efficiency of the machine.

(10) Peculiar and characteristic forms of energy which are the special produce of some organism or class of organisms, and not essential elements of its operation as a vital machine, but which are employed occasionally as the special provocation to which they respond comes into action.

Such is the internal work last mentioned—that of the brain—where it is not the useful product of the machine; such is the energy expended in the production of the poison of the serpent, the secretion of offensively odorous fluids in many animals and, perhaps, the honey producing glands of the bee may be thus classed. The most remarkable, and, in this connection most important, illustrations of this class, are found in the generation and use of the electric fluid by the torpedo and gymnotus and the production of light by the glowworm and firefly.

Hibernating animals exhibit a peculiar modification of the action of the vital functions; their whole purpose, during hibernation, being to insure of the continuance of the physical operations of circulation and respiration by the employment of the previously stored energy of the accumulated fat of the body. Very little tissue is wasted or repaired, and the whole system is simply preserved in action through a period of

temporary suspense of the life of the creature. That this may be done by the employment of pure hydrocarbons indicates that only energy and not material is required, for no nitrogenous aliment is absorbed or assimilated.

The measure of these various quantities of energy, useful and wasted, necessary or incidental to the purpose of the existence of a machine or its application to useful work, is, in the case of the external useful work of a laboring man or animal, easily and accurately made; but all the other items are very difficult, and usually, at present, at least, impossible of more than approximate measurement, even if any clue can be obtained at all to their methods of action or their absolute and relative quantities. We have not yet discovered the nature of the primary methods of transformation of the energies imported, as latent, into the system, or even what energies are active in the production of the work of the brain and nervous systems and in the automatic operation of the machine. We know enough, however, to prove that the animal machine is a motor of very high efficiency as compared with the prime movers devised by man (his thermodynamic engines, at least), and to indicate, if not to prove, that the machine is a thermo-electric, chemico-dynamic, electro-dynamic, or chemico-electric apparatus, or else a prime mover in which some unknown form of energy, acting by as yet undiscovered methods, is transformed more economically than in any case familiar to the man of science or the engineer of our time.

The power of animal machines varies greatly with the race and work. Investigations of the quantity of work per pound of the animal machine have been made by the students of aviation, which throw some light upon the problem in hand.[1] Thus Dr. Smith measured the lifting power of a pigeon, as registered by a dynamometer, and computed its expenditure at 160 foot-pounds per pound of bird, or about 200 pounds weight of bird per horsepower. Alexander computes 270 foot-pounds per pound, 120 pounds weight per horse-power. Penaud finds the following, which are thought to be more exact figures:

	Pounds per horsepower.
Peacock	66
Pigeon	57
Sparrow	48
Seapie	26

Were the weight of the pectoral muscles, which actually perform all this work, made the basis of these calculations, these figures would range from 13 to about 5 pounds only per horsepower, thus giving the limiting weight of motor machine. The actual work of rising in the last cases is greater by the amount of slip in the wings, and the bird computed to give 60 pounds per horsepower is more nearly 20 pounds, and the last given figure becomes more nearly 5 to 2 pounds than 13 to 5. In full flight, the demand for power is much reduced, and becomes

[1] Progress in Flying Machines. O. Chánute. Page 39.

probably 500 foot-pounds per pound, or at the rate of 0.015 horsepower per pound, 66 pounds of bird per horsepower. This flying machine is proportioned to give the higher power at starting; the lower in steady working. Their emergency performance is thus probably three or four times the average for the day's work. This is also a fact illustrated in common experience with men, who, developing one-eighth of a horsepower for an average day's work, can exert a half horsepower for two or three minutes, a full horsepower for a few seconds. The aggregate power of the machine varies from an indefinitely small quantity with the smaller creatures to 140 horsepower, as estimated for the whale swimming 10 knots per hour.

The heart is, perhaps, the most powerful and enduring of all the muscular structures of the system. Helmholtz has computed that this organ can, on the average, raise its weight at the rate of 6,670 meters per hour. He found that the locomotive, climbing heavy gradients, in the cases investigated by him, at that time, could rise 800 meters in the hour, unloaded. He therefore concluded that the heart, considered as a machine, was eight times as effective as the locomotive. Presuming that his locomotive had an efficiency of 10 per cent, this would make the heart, were it self-contained and a prime motor, exhibit an efficiency of energy-conversion of about 80 per cent. This supposition is, however, by no means correct.

Fick estimates the efficiency of energy transformation in the useful work of the muscle at one-third to one-quarter, the remainder of the total energy supplied being consumed in internal work and wasted directly or indirectly as heat.[1]

Chauveau points out the fact that the efficiency of the muscle varies enormously with time and method of contraction and extension and magnitude of load. In the case of the muscles of the automatic—the vital—system as those of the heart and lungs and digestive organs, it is probable that the conditions are those of constant maximum efficiency, and the figure attained would seem, from other considerations, to be likely to be found comparatively large, and, for the machine as an energy transformer, immensely greater than is ever attained in nonvital motors of the thermodynamic class. The energy transformation is presumably never thermodynamic, but is, directly or indirectly, dynamo-thermic, and the heat of the muscular system is a product, not a source, of useful work, and an excretion, not a food.[2]

It has been seen that the food required by the average workingman contains about 12,000 British thermal units of energy when resting or doing little work, and about 16,000 when at hard work. It would thus appear that the work of the laborer, for which he is paid, represents about 25 per cent of all the energy expended by the vital machine in external and internal work, heat-producing and wastes. This means

[1] Experimenteller Beitrag, 1869; Ueber die Wärmeentwicklung, 1878.

[2] Chauveau. Travail Musculaire, page 233.

that it performs one-fifth of a horsepower of commercially valuable labor, and, assuming all work concentrated into the workingday, three-fifths of one horsepower, mainly, in the work of the organism itself.

A day's work, even for the average workman of full working power, varies greatly with the nature of the work and the method and facilities of its performance, and the same is true of the horse and all other animals, but usually in less degree. The most powerful horses may be expected to develop, as an average, two-thirds of a horsepower for eight hours a day, or 12,000,000 foot-pounds per day, very nearly, under favorable circumstances. The work of a man is variously given by different writers, but it is usually stated to be not far, at best, from 2,000,000 foot-pounds per day in the treadmill, ascending mountains and stairways when his own weight is the useful load, and carrying burdens on a level. Weisbach gives as maximum figures 1,935,360, Rankine gives 2,088,000, while Ruhlman states the work of a Prussian soldier, carrying a knapsack and other accouterments weighing a total of 64 pounds, as about 3,000,000 foot-pounds. We may safely take 2,000,000 foot-pounds per day as a figure to be compared with the 10,000,000 foot-pounds of energy supplied, and as giving a fair maximum for the efficiency of the animal considered as a prime motor.[1] It is 0.125 horsepower for eight hours, 0.04 for the day.

The efficiency of the animal machine as an apparatus for the performance simply of external work is on the basis here taken,

$$E = 2{,}000{,}000 \;/\; 10{,}000{,}000 = 0.20,$$

20 per cent. This happens to be just the efficiency of the best recorded steam-engine performance to date.

The efficiency of the vital machine considered as a motor is high. Haller, about 1840, had applied the then new principles of thermodynamics to the action of the vital elements of the system, and had suggested that the heat of the body was at least in part due to the friction of the circulation. Joule found by experiment that the passage of fluids through tubes gave rise to heat, and gave the correct explanation as early as 1843. In the now famous paper of Joule, dated 1846,[2] he concludes:

The duty of a Daniell battery, per grain of zinc, is 80 pounds raised 1 foot high—about one-half the theoretical duty—i. e., its efficiency is about 0.50.

The duty of a Cornish engine, per grain of coal, is 143 pounds raised 1 foot high, an efficiency of 0.10.

The duty of a horse, per grain of food, is 143 pounds raised 1 foot high, "which is one-quarter the energy due its combustion," an efficiency of 0.25.

[1] The Animal as a Prime Motor. R. H. Thurston, section 17, page 50; section 18, page 53.

[2] Philosophical Magazine, 1846. Memoir of Joule, by Osborne Reynold, 1892, page 100.

Joule thus, at the middle of the century, had found the animal, taken as a prime mover, to be two and a half times as efficient as the best engines of his day, one and a quarter times as efficient as the best engines of our day, the close of the nineteenth century.

This figure is corroborated by many independent experiments and computations. Joule, as above, put the work of horse and man at about one-fourth, sometimes as low as one-sixth, the dynamic equivalent of the food supply. Hirn found substantially the same figure as is above deduced by measuring the work and the exhalations of carbon-dioxide and of moisture by his inclosed treadmill operators. Helmholtz deduced 20 per cent. also, from the same experiments. Joufret takes the work of the man at 280,000 kilogrammeters and obtains 21 per cent. by the day. rising to 37 per cent, short intervals and actual expenditures of energy and proportional supply being taken.

We may thus, without much doubt, conclude:

The efficiency of the animal machine, assuming that only external, so-called useful work is reckoned as the product, and the full dynamic equivalent of the energy latent in the food supply being taken as unity, is about 20 per cent.[1] Hirn's experiments with his inclosed treadmill gave efficiencies from 17 to 25 per cent, the lowest being given by "a lymphatic youth of eighteen," the highest by a strong laborer of the age of forty-seven. The average is precisely that computed by the method pursued above.[2]

Our computation, however, should be checked by the introduction of the quantity of rejected. unassimilated food, if we are to learn the real maximum possible efficiency of the animal machine motor.

The factor of digestibility is probably with the animal machine, human or other, when in good health and normal, between 75 and 90 per cent, averaging not far from 80 or 85 with the customary healthful foods. With domestic animals Professor Woods finds this factor to range all the way from about 50 to approximately 90 per cent.[3] This is confirmed by many other investigators, and the assumption of 85 per cent as a fair maximum is probably perfectly justifiable, with all the familiar forms of the vital machine in good order.

In the case of Weston, the pedestrian—studied by Dr. Flint—the proportion of food utilized being taken as measured by the ratio of nitrogen absorbed in food to that excreted in chemically different combinations, the efficiency of nutrition, the "factor of digestibility," in one sense, was, when quietly training without excessive exertion and with very moderate exercise, and as an average for five days, 86.6 per cent.[4] It is probable that a good digestion and assimilation should be expected to attain an efficiency of 90 per cent, and that 10 per cent of

[1] The Animal as a Prime Motor.

[2] Ibid., p. 43.

[3] Reports of Connecticut Agricultural Experiment Station.

[4] Muscular Power, page 84.

the food, or less, might be expected to be wholly wasted. Very nearly this efficiency was attained by the same individual during five days of recuperation after a five days' walk of 317.5 miles.

The food of the human prime motor has been seen to yield from about 2,500 calories, 10,000 British thermal units, 7,800,000 foot-pounds, nearly, when doing little or no work, up to 4,000 calories, 16,000 British thermal units, 12,500,000 foot-pounds, nearly, when doing a maximum day's work. This would seem to indicate that the internal work of brain, nerves, muscles, and other organs of work and thought and heat production must be about three times the total external work of a working day, and this, in turn, would again make the efficiency of the vital machine one-quarter, 25 per cent, corresponding once more to the maximum given by Hirn's's direct experiments.

Reviewing what has been thus far collated, it will probably be admitted that the following may be taken as a fair estimate of the efficiency and energy distribution of the average representative human prime motor, assuming 10,000,000 foot-pounds supplied and 85 per cent of the food to be digested:

The animal machine—Receipts and expenditures—Efficiencies.

Received food-content.		Energy utilized.	Per cent of energy available.	
Total receipts (foot-pounds)	10,000,000			
Loss unassimilated	1,500,000			
Available and utilized		8,500,000	85	100
One day's labor, maximum		2,000,000	23.5	20
Heat rejected [1]		3,700,000	43.5	37
Thought-energy		500,000	5.9	5
Internal work other than friction		2,300,000	27.1	23
Wastes by nonassimilation, as above				15
Total		8,500,000	100	100

[1] Dalton.

Where the machine is a *thought-machine*, and not primarily a prime motor, the efficiency may be quite different, as will be seen later.

The wasted energy of the vital machine, when considered merely as a work producer in the ordinary sense of that term, consists of the various internal energies expended in the operation of the machine, the misapplied mechanical energy of the twenty-four hours, and the heat radiated and conducted from the body and exhaled from the lungs. Could all these wastes be suppressed, the efficiency of the machine would be unity as a prime motor. Precisely what are these energies and their respective amounts is, as yet, unknown; their aggregate has been seen to be 80 per cent. To what extent either or all may be suppressed, as our knowledge of the machine enables us to employ it more and more intelligently, no one can yet say, except that it is known that the losses of heat from the exterior of the body may be kept down to a

comparatively small amount, and, if necessary, made minute, by properly clothing it in nonconducting materials, precisely as nature clothes the birds and the other wild creatures. If the suppression of this loss results in corresponding increase in energy-conversion, in useful directions, the efficiency of the machine is to that extent exalted. It is certain that some loss of heat externally is necessary to preserve the activities of organs of the body, by giving a needed difference of temperature between the surface and the interior, and to carry away energy in its final, thermal form: and mankind has, from the beginning, sought to reduce this waste by covering the body with skins, woven tissues, and other forms of material fitted to check the outflow.

The source of animal warmth and heat energy has been for generations the subject of study and experimental research by the best physicists and biologists. According to Jamin, Messrs. Halles and Cigna and Black and Priestley showed that the products of respiration were chemically identical with those of combustion. Lavoisier confirmed this conclusion, and proved that the oxygen inhaled was not all accounted for by the exhalation of carbon-dioxide, but a balance must be sought in the production of water by union with hydrogen. He attributed the vital functions to the oxidation occurring in the lungs, and circulation to digestion and to the regulating action of transpiration. Regnault and Reiset, measuring the volumes of carbonic acid produced, found that the larger the proportion of vegetable food the greater the amount of this oxidation; while the combination of oxygen directly with the carbon of the nutriment sometimes gave an item in the balance of the account, its rejection occurring with the fluids of the system, as in uric acid, this proportion being the greater as the food was, in larger part, flesh. They found a small amount of nitrogen passing off, presumably rejected from the disintegrating tissues. Boussingault reached the same conclusion by determining the quantities of solid and liquid taken into the body and rejected from it. Lagrange, Spallanzani, Edwards, and Magnus ascertained that the oxidation occurs in the circulation and the capillaries. Despretz and Dulong found the heat produced by the vital apparatus to be about nine-tenths the quantity which would result from complete oxidation, in equal amount, in the air.[1]

The source of vital and muscular energy is easily identified, and it is well known that the function of digestion is to render available the potential energy of the foods by reducing them to solution in fluids capable of easily and rapidly and completely entering the constitution of the blood, to be distributed to points in the system at which their stores of potential energy may be made available in kinetic form. Precisely how this latter operation of transformation occurs is still unknown; but Claude Bernard, about the middle of the century, called attention to the action of the hepatic system in the production of glyco-

[1]An interesting corroboration of recent measures of the coefficient of digestion.

genic matter, and later investigation has shown that glycosic matter is distributed throughout the animal system from the liver and through the circulatory system into the capillaries, where it largely disappears and carbon dioxide comes into view. It is now well understood that the oxidations and the energy transformations essential to animal life and activities occur through reactions between the oxygen in solution in the blood of the arteries and the combustible elements accompanying it, which chemical operations take place in the depths of the tissue cells, and, perhaps, in the capillary vessels. It is also now admitted that the quantity of action is probably proportional to the loss of sugar and of oxygen, and to carbonic acid replacing the lost glycose as a product of its oxidation.[1] Since these chemical combinations are invariably low-temperature combustions, and since they are vastly greater in quantity in the active than in the passive muscle, and since the heat ultimately derived is the excretum of the system and the final result of energy transformation, it may fairly be concluded that an intermediate transformation, or series of transformations, as yet unidentified, either qualitatively or quantitatively, constitutes the physiological method of production of work. Glycosic substance is not found concentrated in any considerable quantity in the tissues, except in the liver, the organ in which it originates, and the only conclusion would seem to be that glycogenesis is the one extremity of a chain of transformations, of which heat constitutes the other. In this sense the hepatic gland is the source of muscular power as well as of animal heat. It is this fact which makes the flow of blood to the working part, and the volume of its channels, measures of the energy there applied.[2] The weight of blood flowing through a muscle at work was found by Chauveau and Kaufmann to be about 85 per cent of the weight of the muscle itself, each minute of working time, for full load. Its amount varies with the work performed, external and internal. The circulation, with the muscle in repose, was found by the same investigators to be about one-fifth as great as when full work. The succession of changes is thus, probably, as follows:

(1) Potential energy in foods is rendered available as a source of kinetic energy by change of the foods into the various constituents of the blood by chemical action and the expenditure of some probably small net amount of chemical energy.

(2) This available potential energy is transferred to the capillaries by the blood, and its elements are selected by each organ for its own special development of mechanical work or of other and active energies.

(3) Chemical combinations take place, resulting in the production of active forms of energy, applicable to the special work of the organ, as mechanical work in the muscle, chemical action of characteristic kinds in the glands, nerve power in the nervous system, and the accessories of thought in the brain.

[1] See Chauveau and Kaufmann. Comptes rendus, T. CIII, 1886.

[2] Chauveau and Kaufmann. Comptes rendus, T. CIV, 1887.

(4) The internal energies, though useful, objective forms, each being utilized in the performance of its special work, are subject to a final transformation, and are at last converted into heat and passed outward, to be excreted by the skin and the lungs.

The latest researches indicate very positively that the production of heat in the vital prime mover is partly due to nutrition and tissue repair, or rather its breaking down, and not all necessarily derived from the simple and direct oxidation of the combustible matter of food. It is even uncertain whether the potential energy of food considered as a fuel and of its combustion in air is to be taken as precisely measuring its energy available for the work of the vital machine. Chauveau considers the glycogenic product of the liver distributed to the tissues the source of all mechanical and thermal energy. The sound animal machine can work vigorously about eight hours a day; the remaining sixteen hours are devoted to repair, reconstruction, and energy storage. Eight hours each day, one-third of life, is given especially to the reparation of the brain and mental powers.

Dr. Edward Smith has shown, by experiment upon himself, that the inspiration of air and the production of carbon dioxide may vary in the proportion of 1 to 10, accordingly as the individual lies sleeping or actively exerts himself in the treadmill or in running at top speed, the exhalations of CO_2 ranging from 5.5 grains to 45 grains per minute.[1] The quantity becomes, for the given case, 6 grains when standing, 20 when walking, and 25 or 30 when walking rapidly. The variation seems to be approximately, in Smith's tables, as the square root of the speed of the pedestrian. Since the total work of the machine must vary as the velocity of overcoming a fixed resistance, as the cube of velocity where the resistance increases with the speed square, as is here presumably the fact, it would seem from these facts that the interior resistance must be a rapidly increasing proportion of the total work performed, internally and externally, a deduction which is confirmed by constant and familiar experience. The experiments of the same investigator, however, seem to prove the variation of the exhalations when at rest, directly with the difference between the external and the internal temperatures; which, if corroborated fully, would indicate the heat of oxidation in the body to be ordinarily employed principally in the maintenance of its warmth at the standard point. This makes it advisable to ascertain more exactly what energy is measured by the chemical actions resulting in the production of other rejected compounds, solid and liquid, and to learn, if possible, whether chemical action in one case produces the demanded thermal energy and in others the required chemical or other motive energy.

These various deductions indicate that one-tenth or thereabouts of the energy of oxidation in the tissues of the body and in its capillaries finally produces work of various kinds; that nine-tenths passes as

[1] Foods. International Series. New York: D. Appleton & Co.

heat; that the efficiency of energy conversion is thus 10 per cent. On the other hand, the fact that external work alone gives transformation of 20 per cent shows that both internal and external work must find ultimate conversion into heat from some other and antecedent form of energy of food conversion and chemical action.

Rejected heat energy increases rapidly with increase in the amount of work performed by the machine, and this seems to confirm the idea that the expenditure of internal energy in the accelerated operations of circulation, respiration, and nutrition must find ultimate conversion into heat and rejection in that form. The disappearance of thermal energy observed by Hirn is proof of this action. Hirn also found that the total heat exhaled exceeded by one-third that computed, and thus proved that it must be derived, in part at least, from other processes than combustion. The quantity was five calories when resting, about half as much when at hard work per gram of oxygen inhaled. Mental effort and work have precisely the effect of manual labor in this increase of the heat waste and conversion of energy. The source of energy as an effect of oxidation would seem to be the food taken into the system and the broken-down tissues of muscle, bone, and nerve, while the office of the food supply is to replace this tissue and to furnish the energy of chemical action as well.

Dalton[1] and others take the heat waste of the human machine as about 200 British thermal units per hour, 1·28 British thermal units per pound nearly, or a total for the day of 4,800 British thermal units, equivalent to 3,734,400 foot-pounds. Assuming the possibility of complete suppression of this as waste, or, what is equivalent to the same thing, its application to internal work of equal value with the energy applied to useful external work, the efficiency of the animal machine becomes

$$5{,}734{,}400 - 10{,}000{,}000 = 0{\cdot}57 + ;$$

over 57 per cent, and exceeds that of any known form of thermodynamic machine in actual use nearly three to one.

Whether the suppression of this waste, with corresponding gain in useful conversion of energy, can be effected remains uncertain and is perhaps unlikely to be practicable, although animals and human races in the Tropics often live for long periods in temperatures at which no conduction or radiation of heat is possible, and must depend entirely upon evaporation of moisture from the exterior of the body for its distribution. Since it certainly, in part at least, represents the retransformed energy of internal work, it would seem probable that only by effecting a balance between internal and external work of that class could this waste be completely suppressed. This is probaly impossible with the vital engine, but nothing is known that would indicate similar necessary limitations in any artificial machine in which the essential

[1] Human Physiology. Philadelphia, 1875, page 302.

transformations of the vital machine may in some way possibly be illustrated.

As has elsewhere been suggested, it seems certain that all the internal operations of the body, all the various methods of energy transformation, must result in final reduction of their resultant total to the form of heat energy, and in that form they pass away from the system. This conclusion is confirmed by the experiments of Rubner, who finds that the radiated heat of the animal body precisely measures the calorific power of the food utilized by assimulation.[1]

The internal work of the vital machine, as now computed, amounts to 43 per cent of the energy supplied less the amount of rejected potential energy of unassimilated food. Neither quantity has as yet been precisely determined. Estimates have been made, however, and possibly sufficiently approximate for present purposes.

Letheby, for example, proposes the following for an average day of the average workingman at his usual vocations involving some manual labor:

Foot-pounds, external work, actual labor	1,011,670
Work of the circulation	500,040
Work of respiration	98,496
Total foot-pounds	1,610,206

Adding to this probably very rough estimate the 3,734,400 — 598,536 = 3,135,864 for heat not due to these causes, we have a total of 4,746,070 foot-pounds, or about one-half of all the energy supplied. Reckoning the work, as before, at 2,000,000 foot-pounds, the total becomes five-eighths the energy supply.

This leaves at least three-eighths to be accounted for, and if we may take the proportion of blood taken to the brain as a measure of its demand for energy, and, as estimated by Flint, at about 10 per cent, we still have about 25 per cent as unaccounted for; but it is certain that a part, perhaps a large part, of the heat rejected from the system comes of internal fluid friction and energy transformations, and it is also certain that some of the food escapes digestion and assimilation. In fact, the loss in the latter form of supplied energy has been computed in some cases as fully 25 per cent.

It would thus appear possible, if not extremely probable, that the full amount of the potential energy of the food actually assimilated may be accounted for in one or another form of the resultant energies visible or sensible as external, and as essential internal, work in the vital machine. Just what internal work the external heat flow may represent it is impossible to say positively; but assuming that all the energy expended in the circulation of the fluids of the body, all the work of friction so appears, and that all energy of internal mechanical work of other sorts and of all chemical processes occurring within the

[1] Zeitschrift für Biologie, XXX, 1893, page 73.

system also is thus rejected as heat, and assuming that the energy of brain and nerve action is transformed into mental and unmeasurable energies of which we have no dynamic equivalent yet established, the animal machine, as represented by the human body, may be taken as having an efficiency measured by the ratio of the sum of useful muscular labor and brain work to the energy supplied.

This is now seen to be probably not far from 30 per cent, and the machine is, thus viewed, one and a half times as efficient as any existing steam engine.

If the use of the machine may be taken to be the production of muscle and brain work, and of the heat required for the comfort of the system considered as an intelligent creature, the efficiency becomes the sum of these three quantities, divided by the total receipts of energy, or substantially two-thirds, the only waste on this basis being that of unassimilated food, and the energy of formation of chemical compounds, of heat, and of dynamic energy, unutilized, in a comparatively small proportion.

Brain work is the task and thought the product of the professional man. The mass and weight of the brain give us some interesting data for consideration, if not throwing important light upon the problem in hand. The average weight of the brain of a man is about 3 pounds, perhaps 50 ounces; that of the average woman is 10 per cent less, about 45 ounces. High brain weights are 53.4 ounces, the weight of that of Agassiz, up to 64.5, that of Cuvier; while low weights are indicative of reduced working power, if not of capacity for intellectual action. It is, however, true that the largest brains have been those of the idiotic and the insane, and that the greatest genius sometimes possesses a brain of but average size or even somewhat less; yet insanity and idiocy only prove, in most cases, disease of the ordinary brain of whatever size, and individual cases afford no evidence pro or con. The important fact is that size of brain increases with the intelligence of the race, and that when the weight falls below about 2 pounds, two-thirds the average for our own race, intelligence is usually lacking. Cerebration only occurs, efficiently, with larger proportions of gray matter.

The average weight of the male brain in African races is about that of females of the European races, and that of their females is 10 per cent lower. The weights in Australian races fall to that of the African female in the case of the male, and 10 per cent below this for the female, or 39 ounces. The weight never exceeds 55 ounces, except among the most civilized races. The bodily functions may be maintained and manual labor performed with very low weights, as healthy idiots have been known having brains weighing less than a pound (8.5 to 10.6 ounces). The cerebrum constitutes 87 per cent of the cranial contents.

The compactness and firmness of the brain substance and the comparatively small quantity of blood with which it is saturated in its

ordinary healthy condition, indicate, probably, a slow building of tissue and construction of the gray matter constituting the brain material proper, and is, perhaps, also to be taken as evidence that the organ is not, like the muscles, in the opinion of many physiologists operative by the destruction of its own substance. The proportion of nutriment suitable for each organ, presented by the blood, varies considerably, and it may be the fact that, for this reason at least, the volume of blood sent to the brain is not a gauge of the energy supplied it in that form; but the probably slow construction of the tissue of that organ, and the comparatively small proportion of nerve and brain-making elements in the blood, are in accord with the hypothesis that some approximation to the ratio sought may be thus obtained.

The proportion of blood flowing to the brain would make it appear that about 15 per cent of the potential energy supplied the body is expended in brain work. The fact that a loss of one-third the average weight results in loss of power of cerebration possibly indicates that one-third the brain power is devoted, in civilized races, to intellectual work. The fact that life and bodily health may persist with one-third the average allowance of brain would seem to show that one-third the normal brain action may be required for the conduct of the purely animal operations of the system. The corollary of these two deductions would seem to be that the normal thinker expends one-third his brain power upon the vital machine, one-third upon the incidental and accidental cerebrations of life, and one-third upon real, purely intellectual work. But the size of brain and its quality are both known to be factors in the determination of the magnitude and nature of its product intellectually, and it is very possible, probable indeed, that the intellectual mind, with a brain well adapted to its use, not only has an instrument capable of doing more and better work than the average, but makes more use of that instrument than does his neighbor of equal brain weight. It is for this reason, in part, that the figures here assigned for brain work have been fixed upon. As a matter of simple proportion, the human machine, acting as a prime mover simply, develops from 1,000,000 to 2,000,000 foot-pounds of work per day. The best worker is, usually, also most intelligent, and, following the above suggestion, it may, perhaps, be assumed, in default of direct measurement, that the "brainless" worker—using that term in its vulgar acceptation—may perform the lesser amount, 1,000,000 foot-pounds, and that the intelligent worker may, under similar external conditions, produce 2,000,000 foot-pounds, and that the latter may use his brain and consume energy supplied by the average brain in moderate amount as well. If the professional brain worker does less physical labor and more brain work, he may substitute the one for the other, to a considerable extent, and we have assumed 1,000,000 foot-pounds as the measure of a brain worker's day's work, in addition to the labor of carrying on the bodily functions and that of regular, moderate exercise. As yet, however, such figures are little better than guesses.

The efficiency of the thought-machine, as the "brain worker" of modern times has become, can not be estimated with even so much of accuracy and certainty as that of the same organism employed as a vital prime motor and mechanical engine. The considerations presented in the last sections and in some of the earlier portions of this discussion would seem to indicate that the energy demanded by the brain for transformation, presumably, in the operation of the apparatus as the instrument of the mind and the tool of thought, may be fairly taken as between 5 per cent for the case of the workingman giving all his energies to his task, with little time and no strength for mental labor, and for the nonintellectual creatures most nearly approaching man in their constitution and structure, and 10 per cent for the average intellectual product of civilization, up to perhaps 15 per cent in the case of the steadily working professional brain worker. This is mainly to be deducted from the energy applied by the laborer with his muscles to his daily task, and the efficiency account would, in such case, stand as a first and a rough approximation, perhaps, as follows:

The intellectual machine—Receipts and expenditures—Efficiencies.

Received food-content.		Energy utilized.	Per cent of energy available.	
Total receipts (foot-pounds)	8,500,000			
Waste, nonassimilation	1,500,000			
Available and applied		7,000,000	82	100
One day's work (thought)		1,000,000	12	14
Heat rejected		3,000,000	35	43
Internal work, aside from friction		2,000,000	23	29
External work (moderate exercise)		1,000,000	12	14

This estimate makes the efficiency of the mental machine 14 per cent if based upon the energy actually offered it in the circulatory system, or 12 per cent if based upon the total food supply. If the exercise taken can be made also commercially useful, the efficiency, on this assumption, becomes 28 or 24 per cent, and if the essential work of the machine is taken as that of providing its operator with heat and brain power it becomes 57 or 47 per cent, the internal work as here denominated being the only waste except that of nonassimilation of food.

Whatever may be taken as the proper method of reckoning efficiencies from the utilitarian standpoint, it is obvious that, in one form or another, the machine—this vital engine—converts 80 or 90 per cent of the energy received by it into new energies by transformation, and, taking the real waste in the scientific sense as that of the heat rejected, the efficiency for comparison with heat engines—in which but one purpose exists, that of providing a single form of energy, transforming all received into the mechanical form, so far as practicable—it is fair to say that the former, with its efficiency as thus stated at 57 to 65 per cent, excels the perfect heat engine of our time enormously, has twice the highest theoretical efficiency of the best steam engine yet pro-

duced, and three times its actual efficiency under the most favorable conditions yet reported. To attain this efficiency of the vital machine, any heat engine acting under the laws of thermodynamics, as applied to motors with fluid working substances, the only forms as yet devised, must, if we take the temperature of the human body as its minimum, have a range of about 375° F., and a maximum temperature of about 475° F. These should be the limiting temperatures of the machine, if it were a thermodynamic engine operating under any such conditions as are now known to limit the action of the heat engines.

The maximum possible range of temperature in a mass of organic substance of which 50 per cent or more is water, and the circulating fluid mainly a solution of organic substance, can not possibly be much greater than the range between the freezing and boiling points of pure water, but the efficiency of the best heat engine known, even acting as a perfect thermodynamic engine, would not exceed the ratio $180/672 = 0.27$ (27 per cent) and its actual efficiency would probably fall below 20 per cent. The animal—the vital engine—certainly has no sensible range of working temperature, and no elastic working substance like the gases and vapors, but its efficiency, even as a work producer alone, exceeds the above figure, and as an energy-producer its efficiency exceeds that of ordinary heat engines several times.

The correct method of estimating the efficiency of the vital machine is unquestionably that which sums up all its expenditures of energy, thermal, mechanical, mental, and determines the ratio of that sum of all energies, so far as directly contributing to the purposes for which the dweller within the apparatus lives, with the total energy supplied during a period including at least one perfect cycle. Taken in this manner and in this sense, the rejected heat would seem to constitute the only real waste, and the efficiency of the machine, as a peripatetic residence for the soul, would seem to be fairly reckoned at not less than 45 per cent nor more than 65, accordingly as one or the other of the units above taken are accepted—two to three times the maximum efficiency of the best-known heat engines.

The rejected heat energy is precisely like that of the final heat waste of the electric-lighting system—the final form of energy subjected to transformations of greater or less complexity during the process of application, in some definitely demanded phrase, to a prescribed purpose. Rejected heat is certainly not, in the case of the vital machine, "let down" from a higher temperature in the process of thermodynamic conversion, an essential characteristic of that form of prime mover. The machine is evidently not a thermodynamic engine.

PART III.—SPECIAL ENERGY PRODUCTS: ELECTRICITY, LIGHT, ETC.; SUMMARY AND CONCLUSIONS.

Singular and unfamiliar energies are produced by the vital machine, either as incidental to the ultimate purposes of the apparatus, or as special final output for peculiar purposes. For example, it is known

that electricity is produced in the muscular and nervous systems, in vertebrate animals, and that in some cases, as in that of the electric eel, in large quantities, and for peculiar and special purposes of offense and defense. The firefly also produces light for its own special purposes. It is supposed by some authorities that electricity is developed for the use of the internal telegraphic system of all animals and it is a "singular" product only in the sense that we have not yet been able to make ourselves familiar with it and to determine just how it is employed and in what manner it is generated and transformed. In the case of the light producer, the product is "singular" in the sense that it is not only unfamiliar as a system of energy production, distribution, and transformation, but also as being rarely developed. We know only the glowworm, the firefly, and a few other organisms, such as the animalculæ of the tropical seas and certain bacteria, which are capable of transforming energy supplied them into light. In this case it is also singular that the light produced should be almost, if not entirely, unmixed with heat, and in this sense it is the most economical light production known. These two examples of singular product are so important and suggestive, as well as interesting from their mystery, that they demand careful consideration, particularly at the hands of the engineer.

Electricity has long been recognized as a vital energy, and the fame of Galvani, the distinguished professor of comparative anatomy at Bologna (1737–1798) was mainly established by his striking discovery (1786) of what is now familiar to biologist and physicist alike, as "animal electricity," or, as Daguin calls it, l'électricité vitale, the "vital fluid," according to the discoverer himself. The famous controversy which at once arose between Galvani and Volta, the contemporary professor of physics at Pavia, and which led to the publication of Volta's dictum: "When two heterogeneous substances are in juxtaposition, the one always assumes the positive the other the negative electrical state," was a first step toward the determination of the fact that as externally produced currents will always affect the nerves and muscles, so internal currents may always be found capable of affecting external substances. Nobili's discovery of the "proper current" directed from the foot toward the head of the frog (1827), as predicted by Humboldt just thirty years earlier; Matteucci's extended researches of later date, and the still more striking investigations of Du Bois Reymond (1842), have proven both the existence of such currents in the animal machine and a drift, also, of electricity outward from interior of muscle, or nerve, to the surface, which may probably be taken as a "leakage current," due, in part at least, to the fact that, even here, insulation is not perfect. The last-named investigator showed that the more powerful the muscle, in its natural condition, the stronger these electric currents, the heart, for example, exhibiting powerful currents and the muscular system of the intestines a comparatively weak flow. His well-known experiment,

in which the galvanometer is made to reveal a current passing from an unflexed arm to the other side and into the arm, which, contracting its muscles strongly, grasps an object forcibly, especially interests the student of the vital machine as indicating, in correspondence with the fundamental laws of energetics in this case of electric action, as in thermodynamic operations, the reduction of the energy supply by conversion into mechanical work.[1]

The experiments of the Italian physicists and of Dr. Ure on cadavers are familiar proofs of the substitutive value of the electric fluid and the vital fluid, if, indeed, they are not evidence of their identity; and the still more familiar experiences of all who have had to work with electricity in any form at moderate or high tensions may be accepted as more convincing testimony of the relationship of the one form of energy to the other. The discovery by Pouillet and the later investigations of Donné, Becquerel, and others relative to the now well-recognized form of vegetable electricity constitute an interesting if superfluous confirmation of the idea that nature employs the electric current in her work much more generally than is popularly supposed.

The identity of animal electricity with the familiar forms of that energy is perhaps best shown by the fact that where, as in the gymnotus and torpedo, the best known among some fifty such creatures, the fluid is made the means of attack and defense, thus necessarily being given considerable volume and tension, it responds to every test customarily employed to identify and measure the voltaic current.

The assumption, which perhaps may now be fairly taken as possessing a basis of probability, that electrical or some related or in many ways similar form of energy may prove to be an intermediary between the chemical energy known to be a necessary initial action in the reduction to the active form of potential energy supplied to the vital system, and those ultimate energy products—mechanical power, heat, sometimes light, and always physiological manifestations—is strongly corroborated by the facts developed by research in those organisms which most extensively and strikingly exhibit that kinetic energy. It is known not only that about fifty creatures are capable of applying the electric fluid to their own purposes, in defense and in pursuit of their prey, but that all species of the ray family have at least rudimentary electric organs, a fact first stated explicitly probably by Robin. Five species are known to be capable of producing a sensible, often powerful, electric discharge. Muschenbroeck, Walsh, Davy, Becquerel, Breschet, Linari, Matteucci, Moreau, and others, some of whom have been elsewhere mentioned, have shown this fact and have revealed distinctly the identity of this energy of these fishes and other creatures with the electricity now familiar to us in a thousand daily operations. Marey has shown that the discharge is effected by transmission of the

[1] Recherches d'électricité animale. Annales de Chemie de Physique, 3e serie, T. XXX, page 119.

mandate of the will to the storage battery of the animal at substantially the same rate that other nerve actions are propagated.[1] He sums up his facts in a form which suits our present purpose well.[2]

He concludes:

(1) The rapidity of the nervous agent is identical in the torpedo and the frog affected by the electric discharge.

(2) "Lost time" exists and has the same measure in the electrical apparatus of the torpedo and in muscle, and the same is true of its endurance.

(3) The duration of the torpedo's discharge is about the same as the duration of the shock in the case of the electrified frog.

(4) This period is about one-seventh of a second.

Davy produced all the phenomena of voltaic electricity from the vital organism; Linari and Matteucci similarly proved its identity, in action and effects, with static electricity and provoked the electric spark from the animal. If the idea of Fritsch is correct that the electrical generating and storage organs of the creature are derived from the skin, it would seem very probable also that the source of energy transformation from potential to the kinetic, or from stored forms to motor forms, may be found in or under the cuticle. Bayliss, Bradford, and others, however, attribute the currents observed in animals to the flow of fluids, perhaps to simple friction; while Biedermann thinks the katabolic action, breaking down tissue, is the source of the current passing inward, and the anabolic action, constructing tissue, is the cause of the reverse current. If the machine be in any degree electrodynamic, this is a substitution of cause for effect.

Humboldt's account of the employment by the Indians of Rastro de Abaso of wild horses in capturing the gymnotus, at the sacrifice of an occasional horse by drowning, after being disabled by the shocks administered by the enraged gymnotus, and his statement that he himself had received more powerful shocks than he had ever received from the largest Leyden jars, give some idea of the vigor as well as of the character of animal electricity. His experiments with Gay-Lussac, and those of Davy, Becquerel, Breschet, and others, show it to be capable of performing every feat and exhibiting every phenomenon familiar to us as the result of voltaic action at high tension.

All research to date proves:

(1) That the electrical current in the animal system is produced for the purpose of effecting energy transformations of, as yet, undetermined character and extent.

(2) That it is, in the electric fishes at least, developed at will in quantity demanded for its intended work, as in other displays of energy, up to the limit of the nerve power of the individual.

(3) That in all its characteristics it is similar to, if not identical with,

[1] Journal de l'anatomie et de la physiologie, 1872.
[2] Animal mechanism, page 57.

voltaic electricity, and thus unquestionably subject to all the laws of energetics, of electro-dynamics, of electrical physics, and of electro-chemical action.

The velocity of transmission of the nerve impulse is from 90 feet per second in cold-blooded to 100 or 150 feet in warm-blooded creatures—an exceedingly minute fraction of the speed of the electric current over good conductors. It thus requires about the tenth part of a second to telegraph from the brain to the extremities and obtain a response through the sensory nerves or to produce reflex motions of muscles. Du Bois Reymond found the electro-motive force impelling the electric currents flowing in the nerves and muscles of the frog to have the value of 0.22 to 0.25 volt in the nerve and 0.35 to 0.75 volt in the muscle.[1] Should it prove the fact that the active energy is electric and magnetic, the low voltage, if confirmed by measurement of the actually operating currents doing their regular and normal work, would indicate great strengths of currents at low tensions. The time required for action at the nerve center itself is something like 0.05 second.

Matteucci found that the passage of the electric current from the brain toward the extremities produced contractions of the muscles traversed, while the opposite direction of current caused annoyance, if not actual pain, and seemed only to affect the sensory nerves. He thought that this "polar condition" indicated that such excitation by something analogous to, if not identical with, the electric form of energy constitutes the "nervous agency" of the system.

What is known to-day simply shows that electricity of low tension and comparatively large quantity, or some related form of energy, is or may be a product of transformations occurring in the body, having their source in the potential energy of the food supplied, and is the probable intermediary between the directing power of brain and spine and the elements of the voluntary and involuntary systems of muscles; that this energy is probably in constant circulation in continuously acting organs, and intermittently, at least, in those actuated only by the will; and that the evidence of its presence may always be found in its leakage currents. It is certain that the production of electricity may be increased by the special development of its producing organs to such extent as to become a source of power and of safety to its user and of danger to enemies, exhibiting all the characteristic properties of the familiar forms of moderately high-tension currents.

Anatomists familiar with comparative biology know that the electric cells of the torpedo and its congeners are evolved from the under side of the skin, and by a process which seems simply that of muscle-cell production, with modification to its special purpose. This fact may be accepted as evidence, worthy of consideration at least, that the muscles contain within themselves the principle of animal power, and possibly, even, that this power is a modification of, if not identical with, the

[1] Encyclopedia Britannica. Article "Physiology," page 26.

familiar forms of electricity. It is well known that muscular power may reside in the muscle, and that this local potentiality of energy display may be exerted by, and may even act rhythmically in, an organ, as the heart, detached from the body.

Light production by the vital machine illustrates another curious and impressively suggestive method of energy transformation, the nature of which, and the essential prerequisites for which, are still among the mysteries of this ever-present sphinx.[1] The light radiated by the living machine has been studied by many investigators, and something has been learned of its production and its characteristics. It is known to be produced in a superficial, transparent tissue, blanketing the parts of the creature exhibiting luminosity, and containing a fat of peculiar structure and composition, which may be burned at extraordinarily low temperatures, giving out a light almost absolutely free from heat. It can thus be utilized in the animal system and, only light being produced, but a minute fraction of the energy demanded in the production of our more familiar lights is required for this transformation. In its distribution but a fraction of 1 per cent of the energy thus expended takes the form of heat, while in the common gas, or candle, or oil flame 99 per cent of the energy is wasted in the form of heat; worse than wasted, since the heat thus produced is usually a source of discomfort as well as a material loss.

The vital machine, as a light producer, thus appears to have an efficiency of production approximating unity.[2] It has 400 times the light value of the gas flame, 40 times that of the electric incandescent lamp, and 20 times that of the best arc lamp. But the electric current utilized in these cases is derived from heat energy transformed by the heat engine and the dynamo at, usually, the expense of four-fifths to nine-tenths its original potential amount; thus making the light of nature, as developed in the vital machine, from 200 to 4,000 times as efficient as the best and the worst, respectively, among our present artificial lights, if we assume no wastes in the production of the light-giving material. This would be the case if, for example, its wastes of energy, were there any to occur in the process, were to find use in further transformation, or application, in the economy of the system, as the heat of the exhaust steam of a steam engine in a woolen mill often has as great value for heating purposes as if taken direct from the boiler. Could this kind of light be obtained as the product of artificial methods of energy transformation, the result in economy of energy, of power, and of fuel would be among the most tremendous of all the marvelous products of human invention.

Technically stated, the problem is: to produce ether vibrations having a frequency of 5×10^{14} per second, without admixture of other

[1] The Great Problems of Science. R. H. Thurston. Forum, September, 1892.

[2] Langley and Very, on the Heat and Light of the Fire-fly. Smithsonian Contributions to Knowledge, 1892.

periodicities. Tesla attempts it by electrostatic action; nature does it perfectly by what seem to be chemical processes. How shall we ultimately accomplish this seductive task and emulate nature while complying with those economic laws which always control, and often seriously impede, the progress of the engineer?

Vital force and energy, the force and energy which constitute vitality, which are the characteristics of animal life, may easily be shown to be apart from that higher life of the soul and the intellect which constitutes the *ego*, which *is* the individual. They reside not in the brain, or in its directing power, the mind, but pervade the animal frame, and are found active throughout the vital machine. Life, in this sense, is seen in the motions of the decapitated trunk of any animal, and the reptiles often live a long time with brain removed. All the functions of purely animal life continue, and the taking of food, its digestion, the act of respiration, that of blood circulation, and the whole "automatic" operation of the system essential to continued vitality goes on. This independence of the vitality of all mind is seen in the spermatozoa, which live independent lives for hours, and even in some animals, as in the bats, for months at a time. It is seen, very probably, in the white blood corpuscles, which, as they float in the stream of vital fluid, change form, seize upon each other or upon the surfaces of their channels, and otherwise exhibit independent life. In fact it may be fairly presumed that they are themselves the principle of life, its method of importation into the animal system. But this is not all. The vital principle attaches to every part, and the heart, removed from the body, continues for a time pulsating with its own independent life, the vital principle surviving long enough to produce many repetitions of the natural rhythmic automatic movements of the organ. In man—as intellection is entirely unessential to vitality, and, when unconscious, as when sleeping, when under the influence of anæsthetics, when suffering from concussion or other injury to the brain, the whole animal system continues in action with more or less accuracy under the impulse and direction of the vital power—unconscious life continues, in some cases, weeks and months.

The probability that the vital functions are independent of the intellectual and moral life and of brain action is also evidenced by the facts that the muscle, even when excised, quivers with vitality for a time; that it exudes carbonic acid when working; that it reduces lactic acid, decreases the amount of compounds present soluble in water, and increases the quantity of those soluble in alcohol; decreases glycogen, increases sugar; and all this when the flow of blood, with its burden of nutrients and of oxygen, is cut off from it. Blood entering the living and working tissues is always changed in life and issues with a new composition. The tissues are thus "laboratories in which materials abstracted from the blood are transformed."

An excised intestine continues its peristaltic movements for an appreciable time. The heart of the rabbit beats sometimes a half hour

after excision; the right auricle continues after the organ as a whole has become quiescent, and has been known to exhibit motion fifteen hours after death. The same independent and automatic action has been detected in the dog's heart four days after the death of the animal. The cold-blooded animals exhibit still more persistence of this local and independent life of the organ, and the heart of the frog has been known to pulsate with the motions of life, as a whole, for two or three days after removal from its nerve connections. Every organ is a motor; every protoplasmic cell is an elementary vital system.

The motor and other movements of the machine are absolutely independent of the peculiar nervous and mental characteristics of animal life. This is shown not only by the facts elsewhere mentioned in a similar connection, but also by the seemingly intelligent action of the sensitive plants and many other vegetable organisms, by the movement of the vegetable as well as of the animal protoplasms, by the energetic action of the white corpuscles of the blood and of the amœboid cells of both animal and vegetable protoplasms. Heat, light, electricity, chemical, and mechanical stimuli, alike, all provoke displays of motor forces and energies in the simplest known forms of vegetable and animal structure, and absolutely independently of intelligence, will, nervous power, special circulatory and respiratory organs, or of location in the organism of which they form the most elementary part. The rhythmic action of the human heart, the voluntary movement of the animal frame, the entrapping of its victims by the sensitive plant, the motions of the bacteria, the changes of the amœba and the protoplasmic cell are, all alike, exemplifications of the inherent residence of motor energy under conditions which involve entire absence of all the machinery of thermodynamic or electrodynamic motors of any sort as yet familiar to science.

It is thus evident that the vital energy is independent on the one hand of the familiar physical energies and forces, and on the other of the mental powers of intellectual and soul life. It pervades the whole system, as do the physical energies, and may attain great development without reference to the condition of the physical or the psychical energies. The doctrine of Quesne, "psychism," is to this degree afforded some support. But the now universally accepted doctrine of the evolution of the world from an earlier chaos compels us, it would seem, to admit that all energies and forces and all matter aggregate out of space, and Quesne's proposition may be extended to every department of physics and psychics. All space is pervaded by heat, light, electricity, and magnetism; why not with vital and spiritual energies?

The office of the vital force and its energy is apparently to give direction to the coarser physical energy of the muscle. It is the director of the telegraphic current which notifies the energy of the muscle when and how to exert itself. It coordinates the automatic movements, controls the system as a whole, as well as in detail, and is itself the principle of purely animal life. The organ which mainly controls and

directs it, which is constructed to differentiate it from other energies, to give it form and purpose, to afford it a vehicle, is the spinal nerve of the vertebrate and the equivalent organ in other creatures.

The psychical energies, including consciousness, intellection, emotion, which are essential characteristics of the vital machine, and which, in the case of those with which we are principally concerned, at least influence to an important degree its power, endurance, and efficiency, all depend for their effective display and fruitful exertion upon the preservation in good health and perfect form of the upper brain. A touch upon the surface of that organ impairs the action of the mind; the destruction of a ganglion takes away the power of expression if not of thought; the lesion or degeneration of its tissue measures a proportional loss of psychic energy. With the organ sound and strong, its action depends, as every day's experience shows us, upon its nutrition and repair. Like the body, it is seen to be a machine which guides and applies energies derived from external sources. All its energies come ot an initial supply brought through the blood channels from the digested food, and both body and brain exhibit characteristic modes of guidance and application of the transferred and transformed energies originally stored in air and food. Body and brain are apparatus for absorption, transformation, and employment of characteristic forms of energy. Their methods of absorption, modes of transformation, and processes of application constitute important and attractive as well as legitimate problems in physical research. Tracing back the path by which all matter came in from space to construct the material world and retracing the path over which the energies came out of the ether and its accompanying stock of all the energies, are companion problems.

The origin of energies displayed in the vital machine is found in the food consumed, and the apparatus of the body is simply, as is now well proven, employed in the freeing of these energies from their potential form in the chemical affinities of oxygen for carbon, hydrogen, nitrogen, and the elements of various other compounds, and the diversion and direction of the resultant energies of various kinds and always equivalent quantity in the performance of internal and external work. Brain, nerve, muscle, gland, all give proper direction to appropriate energies; none originates energy or has power, intrinsically, of doing work. They are all characteristically and kinematically similar to the organs of the machines constructed by man. But the ultimate physical source of all energies, so far as identified, is the heat and light of the sun; while in turn the source of the energy of the sun's rays is presumed to be the mechanical energy of colliding atoms, molecules, star dust, ali celestial bodies, the comets, planets, suns, worlds. The distinctive energies are simply, as we suppose, different modes of motion of atoms and molecules and masses, if physical; but we find no light yet thrown upon the nature of the more subtle energies of vitality, of intellection, of mind, or upon their relation to matter.

Conclusions of serious import, of singular interest, of engrossing

attractiveness, and of wonderful possible result may be deduced from what has preceded; some of these conclusions are positive and certain, some extremely probable, others bare possibilities, so far as we can now trace them, and the possibilities are of such inconceivable magnitude and importance, should they be found to have a substantial basis, that, great as are the consequences of the positive deductions, the further investigation of the potentialities will undoubtedly be considered by men of science a matter of even superior importance. Some of these conclusions are:

(1) The vital machine is not a heat engine, subject to the thermo-dynamic laws governing all known forms of thermo-dynamic machinery produced by man up to the present time.

We can not assert that it is not a heat engine in the sense of being a machine, which by as yet undiscovered methods directly transforms thermal into dynamical and other forms of energy; but it certainly can not employ expansible fluids and transform energy by their expansion through a wide range of temperature, and it as certainly does greatly exceed all heat engines in efficiency both ideal and actual.

(2) The vital machine is an energy transforming apparatus, in which the supplied energy is employed in useful transformations in far higher degree than in any energy transforming machine or system yet produced by man to render available the potential energy of oxidizable substances.

(3) The vital machine must operate through methods of energy transformation yet unknown to science, though undoubtedly absolutely scientific and intelligible once discovered.

The source of energy is perfectly well known, and the primary steps of the process determined up to the completion of the preparation of the substance containing the potential energy furnished for transfer into the organs of the body and for immediate transformation by chemical action. The resulting products are all probably identified and most of them well understood and quantitatively determinable; but the intermediate processes of transformation of potential into actual energy, and of transformation of one form of energy into another, as yet are veiled from our sight and concealed from our touch.

(4) These methods, whatever their character, produce mechanical energy more cheaply, as measured in energy consumed, than any known prime motor; develop heat at minimum cost in the same terms; in some cases produce electrical energy in considerable quantity and at high tension, by some probably direct transformation; occasionally produce light of almost absolute purity and perfection of economical character, and in all intelligent creatures supply the mind with an instrument utilizing physical energies for intellectual demonstrations.

(5) All these products being considered, this vital machine is enormously more efficient than any apparatus yet invented by the human mind, and illustrates methods of energy transformation which if they

could be applied in industrial operations in place of the heat engines would afford inconceivable amelioration of the condition of the race, and to a less but nevertheless considerable degree of his attendant creatures, both by giving the power of securing the utmost possible duty from our stores of latent available energy, and by prolonging the life of the race by indefinitely removing the period of exhaustion of those stores.

(6) The best evidence yet secured by research seems to indicate that the method of energy transformation in the vital machine is one which directly transforms the potential energy of the food, as developed by chemical combinations, into kinetic form, sometimes perhaps simply by chemico-dynamic change, sometimes by chemico-electric transformation; and this in turn, and possibly also the energy due to oxidation of food, and, to some extent, of the muscle itself, into mechanical power, into the vital energy of the automatic system, and into the form of energy producing brain work.

(7) The vital machine may produce electricity as one principal output of its working processes, and probably by some direct system, without intervention of either heat energy or dynamical power.

(8) The vital machine may produce light energy in substantially unadulterated form, and by some process which does not involve either high temperature or the production of heat or other energies to be rejected as waste.

(9) It seems most probable, in view of what has been here collated, that the vital machine is some form of chemico and electro dynamic engine.

We know that the vital machine is not thermo-dynamic in the sense of being a heat engine of any known class. We find in electricity the apparently next most available form of energy for use in transformation into dynamic and thermal and other forms, and many accept this as a provisional, a working, hypothesis. This was long ago hinted at by the greatest scientific men, the greatest minds, it would perhaps be fair to say, that have illuminated the history of the race. A century ago Benjamin Thompson (Count Rumford), a keen "Yankee" with uncontrollable inclinations toward scientific research, showed to his own satisfaction, and to the extent of proving to others its probability, that the animal system constitutes a machine of higher efficiency than any steam engine.[1] Joule, as long ago as 1846, working with Captain Scoresby, concluded that the animal motor "more closely resembles an electro-magnetic engine than a heat engine," and this is reaffirmed by Tait in our own day.[2] Sir William Thomson, now Lord Kelvin, in his papers of about 1850, adopts the idea of Joule, and introduces the principle of Carnot, and says explicitly: "When an animal works against a resisting force, there is not a conversion of heat into mechanical effect,

[1] Rumford's Essays, 1800.

[2] Tait's History of Thermo-dynamics.

but the full thermal equivalent of the chemical forces is never produced; in other words, the animal body does not act as a thermodynamic engine, and very probably the chemical forces produce the external mechanical effects through electrical means." We have now seen how all investigations made before and since that date, so far as interpretable, point to the same conclusion:[1] that the machine is not a heat engine.

The possibilities of improvement by simulating or paralleling nature are seemingly stupendous. Could the chemical energy of fuel oxidation be directly transformed into dynamic energy; could it even be changed by double or by indirect transformation, as through the intermediary of electricity, and in such manner as to insure a full equivalence of utilizable energy, it is evident that we might anticipate a conversion as economical as we now attain in the transformation of mechanical into electrical energy, and, consequently, many times as large a return for outgo as we at present realize and correspondingly lengthened time of exhaustion of our stores of primary energy. At first thought the possibility of an economic gain in power production, by following nature in energy transformations through processes which involve the organization of a sugar manufactory as a source of fuel supply, may seem somewhat unpromising; but when it is considered that sugars and glycogens are but carbon and water and that the chemist has successfully attacked many other more unpromising cases, as the synthesis of madder, and of the various other commercial substitutes for natural products, the possibilities, even seen from a financial standpoint, are not apparently absolutely to be ignored. Similarly, could chemical energy be directly and fully transformed into light, where needed, and as effectively as nature performs these operations of energy transformation in the vital apparatus, the enormous expenditure, the fearful wastes, now going on even in our production of out-of-door light by the use of the electric arc would be reduced to a fraction of their present amounts and to an insignificant fraction of total costs. Could vital energy be identified and brought under control, or could that mysterious energy which is its servant in directing and producing animal power be securely gained and its processes understood and controlled, it would seem possible that direct transformations of energy—which probably means by influencing molecular and atomic rather than molar motion—might be made possible to man, and all this impressive and wonderful chain of consequences caused to follow.

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[1] Mathematical Papers, Vol. I, lviii, page 505.

RECENT ADVANCES IN SCIENCE, AND THEIR BEARING ON MEDICINE AND SURGERY.[1]

By Prof. MICHAEL FOSTER,
Secretary of the Royal Society.

I.

When fifty-four years ago the school of Charing Cross Hospital gathered itself together for its winter work, among the newcomers was a pale-faced, dark-haired, bright-eyed lad, whose ways and works soon told his fellows that he was of no common mold. To-day I am about to attempt the fulfillment of the duty, which the authorities of the school have done me the honor to lay upon me, of delivering the first of the series of lectures which the school has wisely instituted to keep alive, in the minds of those to come, the great services which that lad's strenuous and brilliant life rendered to the healing art. The trust of the Huxley Lectureship provides that the lecturer shall dwell on "recent advances in science, and their bearing on medicine and surgery." I venture to hope that I shall be considered as not really departing from the purpose of the trust if I attempt to make this first lecture a sort of preface to the volume, or rather the volumes, of lectures to come; and since a preface bears a different paging, and is written in a different fashion, from that which it prefaces, I shall be so bold as, with your permission, to make the character of my lecture to-day different from what I suppose will be that of the lectures of my successors. It will, I imagine, be their duty to single out on each occasion some new important advance in science, and show in detail its bearings on the art of medicine. Each succeeding lecturer will, in turn, be limited in the choice of his subject, and so assisted in his task by the choice of his predecessors. I to-day have no such aid. It seems fitting that, for the purposes of this initial lecture, the word "recent" should be so used as to go back as far as the days of Huxley's studentship. If it be so used, I am brought to face advances in science affecting medicine and surgery so numerous and so momentous that any adequate treat-

[1]The Huxley Lecture. Delivered at Charing Cross Medical School, London, on October 5, 1896, by Prof. Michael Foster, Sec. R. S. Printed in Nature, Nos. 1407 and 1408, vol. 54, 1896.

ment of them as a whole would far exceed not only the time at my disposal, but also, what is more, my powers to treat and your patience to hear. I will not dare so hopeless a task. Nor will I attempt to select what may be deemed, or what may appear to me, the most important of these advances, and expound the bearings on medicine of these alone. I venture to hope I shall best fulfill the duty laid upon me, and meet with your approval, if I single out and dwell on one or two general themes suggested by the history of science during those fifty-odd years.

The first theme is one suggested by a survey of the studies which engaged young Huxley in the school here in 1842. This will bring before us a special bearing on our profession of the advance of science which, though it may not be evident at first sight to everyone, is nevertheless real and important.

Each case of illness is to the doctor in charge a scientific problem, to be solved by scientific methods. This is seen more and more clearly and acknowledged more and more distinctly year by year. Now, it is true that each science has, to a certain extent, its own methods, to be learned only in that science itself; and from time to time we may see how a man eminent in one branch of science goes astray when he puts forward solutions of problems in another branch, to the special methods of which he is a stranger. In nothing is this more true than in an applied science like that of medicine. At the bedside only can the methods of clinical inquiry be really learned: it is only here that a student can gain that kind of mind which leads him straight to the heart of disease, that *genius artis*, without which scientific knowledge, however varied, however accurate, becomes nothing more than a useless burden or a dangerous snare. Yet, it is no less true that the mind which has been already sharpened by the methods of one science takes a keener edge, and that more quickly, when it is put on the whetstone of another science, than does a mind which knows nothing of no science. And more than once inquiry in one science has been quickened by the inroad of a mind coming fresh from the methods of a quite different science. For all sciences are cognate; their methods though different are allied, and certain attitudes of the mind are common to them all. In respect to nothing is this more true than in respect to the methods of medicine. Our profession has been the mother of most of the sciences, and her children are ever coming back to help her. In our art all the sciences seem to converge—physical, chemical, biological methods join hands to form the complete clinical method. This is the real justification for that period of preparatory scientific study which each enactment of the authorities makes longer and harder for the student of medicine. It is this, and not the mere acquirement of facts. The facts, it is true, are needed. Every day the doctor has to lay hold, for professional use, of mechanical, physical, chemical, biological facts. But facts are things which the well-trained mind can pick up and make

use of as it goes along at any time and in any place; whereas the mind which is not well trained will miss the facts or pick up the wrong ones, or put to a wrong use even the right ones which it has in hand.

Now, the ideal training to be got from any science is that of pursuing inquiry within the range of the science according to the methods of the science; in that way only does the spirit of the science fully enter into the man. But such an ideal education is impossible. We are fain to be content in merely making the student know what truths in each science have been gained and how they have been gathered in, such a teaching becoming more and more effective as a training the more fully the student is made to tread in the very steps, and thus to practice the methods, of those who gained the truths.

The more complete the body of any one science the more useful does that science become as a means of training, and hence it is that advance of science has a double bearing on the medical profession. As each science grows, not only does its new knowledge bring to the doctor new facts and new ideas, new keys to open locked problems, and new tools to use day by day, but the incorporated knowledge gains greater and greater power as an instrument to train his mind rightly to use all the facts which come before him.

Let me, in the light of this view, call your attention for a moment to the yoke of compulsory studies under which the young Huxley had to bend his somewhat unruly neck, and compare it with the like yoke which presses, heavily it seems to some, on the neck of the young student of to-day.

I have not been able to find an exact record of the course of studies pursued by Huxley himself at Charing Cross in the years 1842–1845, but I have been privileged to examine the stained and tattered schedule of the College of Surgeons, duly "signed up," for the years 1844–1847, belonging to one who, during some of those years, sat by Huxley's side, who was then and afterwards his friend, and who has won honor for himself and for your school under the name of Joseph Fayrer.

I find that young Fayrer attended during his first year a course of at least 140 lectures with 100 demonstrations on anatomy and physiology, a course of not less than 70 lectures on materia medica, a course of lectures on the practice of surgery, and a course of "The practice of physics," each of not less than 70 lectures, and a course of hospital practice in surgery of not less than nine months. In his second year he again attended the 140-lecture course on anatomy and physiology, and the 70-lecture course on the practice of surgery, and again hospital practice in surgery, taking as well a 70-lecture course in chemistry, a like course in midwifery and hospital practice in medicine. In his third year he once more attended the 140-lecture course in anatomy and physiology, but no other systematic lectures; the rest of his time was devoted to hospital practice. To these demands of the college of surgeons we ought to add, in the case of the ordinary student, the demands

of the company of apothecaries; but the main addition thus caused would be a course of botany.

Such a curriculum differs widely both in nature, extent, and order from that in force at the present day. But I venture to think that if we examine the conditions of the time, we shall find that the authorities of that day were as wise as, possibly wiser than, we of to-day. In judging such matters as these, we and, perhaps, especially they who would drive the student on into learning by the goad of compulsion, must bear in mind that legislative enactments, such as those prescribing a curriculum of study, always exhibit a long latent period: they come into visible existence long after the stimulus which begat them has been applied, long after the need of those things being done which the enactments strive to do has been felt. So long, indeed, is the latent period, that often new needs have arisen calling for yet other regulations before the old ones appointed to meet the old needs have got into working order. Bearing this in mind, we shall find that the course of study prescribed in Huxley's time was wisely chosen to meet the needs of, at least, the time immediately preceding that, if not, indeed, the time itself.

It will be observed that the study of physics, or as it was then more commonly called natural philosophy, finds no place whatever in young Fayrer's schedule, and that the one short course of chemistry, without any practical instruction, which he attended was taken in his second year—in the middle, as it were, of his curriculum, when he was already advanced in his clinical studies.

At the present time the sciences of physics and chemistry have each of them developed into a body of logically coordinate truths, furnishing an instrument of peculiar value for the training of the scientific mind. Moreover the methods of teaching have developed in no less a degree, so that in the laboratory the student follows, at a long distance it is true, but still follows the steps of those who have made the science, and has at least the opportunity of catching something of the spirit of scientific inquiry. In this educational value of these sciences, even more than in the practical utility of a knowledge of the mere facts of the sciences, great as that may be, lies the justification of the authorities when these, desiring to improve the profession by introducing artificial selection into the struggle for existence, insist that all to whom the lives and health of their fellow men are to be intrusted should have learnt at least something of the sciences in question.

In the time of Huxley's studentship both these sciences were in a very different condition. The time, it is true, was one of great awakening. In physics men's minds were busy opening up the hidden powers of electricity; some ten years before Faraday had made an epoch by discovering induced currents; he and others were still rapidly extending our knowledge, one practical outcome of which was the introduction of the telegraph in 1837. But how great has been the onward

sweep in electric science since then; how great the advance in all branches of physics! To realize the great gap which separates the physics of to-day from the physics of then one has only to call to mind that the world had yet to wait some years before Mayer, and Joule, and Helmholtz, and Grove had said their say. In the books which taught young Huxley the laws of physics he found not a word of that great law of the conservation of energy which, like a lamp, now guides the feet of every physical inquirer, whatever be the special path along which he treads.

In chemistry much, too, was being done. That science was in the first flush of success in its attack on the mysteries of organic compounds. Liebig, Dumas, and others were rapidly making discoveries of new organic bodies, and dealing with types and substitution, were beginning to make their way into the secrets of chemical constitution; but then, as indeed for a long time afterwards, progress was taking the form of the accumulation of new facts interesting and eminently useful, but still mere facts, rather than of the gaining of insight into those laws of chemical change of which the facts are but the expression. And the brilliant success of purely organic chemistry was somewhat prejudicing those inquiries in regions where physics and chemistry touch hands, which in these latter days are producing such striking results.

In the days of Huxley's studentship neither of these sciences presented such a body of truths as could be readily used as an engine of mental training, nor had the educational mechanism for thus employing them been developed; a chemical laboratory for the student was as yet hardly known, a physical one wholly unknown. The profession turned to these sciences chiefly for the utility of the facts contained in them. The facts of physics, with the exception of those of mechanism, were but rarely appealed to, and if those of chemistry were in more common use, it was because they threw light on the mysteries of the pharmacopœia, rather than because they helped to solve the problems of the living body. Hence the authority, not without cause, demanded of the student no physics at all, and asked for chemistry only in the midst of his course, when its facts might help him to understand the nature of the drugs which his clinical studies were already bidding him use.

As regards the biological sciences, the time was also one of change, or rather of impending change; the causes of the change were at work, but for the most part were at work below the surface; their effects had not yet become obvious.

In natural history, in what we sometimes now call biology, in botany, zoology, and comparative anatomy, the activity in systematic and descriptive work was great. The sun of the great Cuvier was setting, but that of our own Richard Owen was at its zenith; new animal forms, recent and extinct, were daily being described, the deep was

giving up its treasures, new plants and new beasts, brought home by energetic travelers, were being duly investigated. But this was only a continuation of what had been going on long before.

Of the great biologic revolution which was about to come, there was not so much as even a sign in the skies when Huxley took his seat on the Charing Cross benches, though Charles Darwin was already brooding over the ideas which had come to him in his long voyage.

Two great changes, however, were already beginning—one due to new ideas, the other to improved methods.

The morphological conceptions, of which Von Baer, in his "History of Development," had laid the foundations, destined to make a new science of animal forms, were being carried forward by Johannes Müller in Germany, though, save for the expositions of Carpenter, they had made but little way in this country. Nowhere, indeed, had they progressed far. The man who, perhaps to Huxley himself, was to advance them most, Gegenbaur, was as yet a mere student. Nor, in spite of the beginning made by Von Baer himself, by Allen Thomson, and by Rathke, had embryology made much progress. Kölliker, to whom the science owes so much, had as yet written no line. Still the new ideas were beginning to push.

Of no less importance was the impulse given by the improvements in the microscope. Only ten years before Sharpey, discovering that eminently microscopic mechanism, ciliary action, found that a simple lens was a much more trustworthy tool than the then compound microscope. But in the ten years a great change had taken place, and, during the latter part especially of the decennium, improved instruments yielded a rich harvest of discovery in animal and vegetable life. Prominent among the new additions to truth was increased knowledge of the mammalian ovum, in acquiring which Wharton Jones, Huxley's teacher at Charing Cross, did much. But the most momentous and epoch-making step was the promulgation of the cell theory by Schwann and Schleiden as the decennium drew to its close, and more or less connected with that step was the accurate description by Von Mohl of the structure of the vegetable cell, and his introduction of the word, which, next to the word cell, has perhaps had the most profound influence on the progress of biologic science—I mean the word protoplasm.

Of this wide field of general biologic knowledge the college of surgeons at that time took no heed, or at least made no formal demand. It is true that part of it found its place in the lectures on anatomy and physiology, and in the consequent examinations, but only a small part. It is also true that the lecturer on materia medica had by custom license to roam over almost the whole of nature, and the student in learning the nature and use of drugs took doses of heterogeneous natural history; the mention, for instance, in the Pharmacopœia of castoreum being made the occasion of a long disquisition on the biology of the beaver.

But in this the end in view was the acquisition of facts, not training in scientific conceptions and ways of thought.

The botany, it is true, which unasked for by the College of Surgeons, was insisted upon by the company of apothecaries, though made compulsory on utilitarian grounds as an appendage to and introduction to the Pharmacopœia, did serve the student in an educational way, teaching him how to appreciate likenesses and differences, even small ones, and how to distinguish between real and superficial resemblances. But the time he spent on this was too brief to make it—save in cases where a special enthusiasm stepped in—of any notable effect.

Of the then conditions of that biologic science which comes closest to the profession of physiology, I will venture to say a few words, though I will strive to curb my natural tendency to dwell on it at too great a length.

A great master—Johannes Müller—had a few years before written a great work, The Outlines of Physiology; a work which the wise physiologist consults with profit even to-day, noting with admiration how a clear strong judgment may steer its way through the dangers of the unknown, and the still worse perils of the half known. A study of that work teaches us the nature and extent of the advanced physiology, which at that day an accomplished teacher like Wharton Jones might put before an eager student like Huxley, and we may infer what the ordinary teacher put before the ordinary student, each perhaps then, as since, eager neither to give nor to take more than the statutory minimum.

When we look into the past of science and trace out the first buddings of what afterwards grow to be umbrageous branches, it sometimes seems as if every time, and almost every year, marked an epoch; it seems as if always some one was finding out something which gathered into greatness as the following years rolled on. But even bearing this caution in mind, the end of the thirties and the beginning of the forties of the present century do seem to mark a real epoch in physiology. All along the line accurate, careful observation, quickened by the rapid growth of the cognate sciences, was taking the first steps to replace by sound views the sterile discussions and scholastic disquisitions which had hitherto formed too large a part of physiological teaching. The first steps had been taken, but the most marked advance was yet to come.

Though the observations of Beaumont had a few years before, by proving that gastric juice was a real thing, and demonstrating its properties, shown the nature of digestion in its true light, the older fermentative and other theories were not yet abandoned by all. Though the conversion of starch into sugar had been recognized, and pepsin had been discovered, the exact action of the digestive juices had yet to be learned; that of pancreatic juice was almost unknown, and bile still reigned as the king of enteric secretions.

In the physiology of respiration the view that the carbonic acid of expired air was formed in the lungs by the oxidation of the carbon of the blood, still found strenuous support; for Johannes Müller found it necessary to argue at great length that the researches of Magnus on the gases of the blood had placed the matter in its true light. It had been suggested that the red corpuscles were in some way also special carriers of oxygen from the lungs to the tissues, but Müller could not regard this as anything more than a mere supposition.

When it is borne in mind that injection with mercury was the one method employed for tracing out the course of the lymphatics, it will be readily understood how imperfect was the then knowledge of the lymphatic system. And when it is also remembered that though Dutrochet had long before used osmosis to help in the interpretation of the movements of liquids in living tissues, the exact researches of Graham had yet to come, it will also be understood why, when questions of absorptions and cognate questions of secretion came under consideration, they were dealt with as questions in such a condition are dealt even nowadays; much was said about them because little was known.

Though Poisseuille, taking up the matter where it had been left by Stephen Hales in the foregoing century, had begun, and the brothers Weber were just continuing, the work of placing our knowledge of the mechanics of the circulation on a sound and exact basis, and though the then teaching of the mechanical working of the heart did not differ widely from that of to-day, the gap which separates the then knowledge of the circulation, even in its mechanical aspects, from that which we possess to-day, is seen in all its width when I remind you that Carl Ludwig's first paper was not published until Huxley had ceased to be a student—until the year 1845. As to all that great part of the physiology of the vascular system which concerns its government by the nervous system, I will only say that in Müller's great work may be read the pages in which he deals with the conflicting opinions and indecisive observations as to whether the brain and spinal cord have any influence over the heart-beat, and in which, marshaling with logical force the arguments for and against the opinion that the blood vessels have muscular fibers in their walls, finally decides that they have not.

In the physiology of the nervous system a momentous advance had been made some few years before, in the early thirties, by the introduction, through Marshall Hall, of the idea of reflex action. This was rapidly supplying the key to many hitherto unsolved physiological and clinical problems. The special functions of the several cranial nerves were being worked out by Majendie, Reid, and others. The former (with Flourens) was also making many experimental researches on cerebral lesions; and, in another line of inquiry, Bidder and Volkmann were preparing the way for discoveries to come by their important studies on the sympathetic system. The physiology of the senses was being vigorously pushed forward by Johannes Müller; but the reader

to-day of Müller's volumes cannot but be struck with the smallness of the space (if we omit all that deals with the senses) which he allots to the nervous system when we compare it with what is demanded in the present day; and no little part of even that limited space is taken up with a consideration of the laws of those "sympathies" which gave to the sympathetic nerves their name, but which have long since dropped out of sight.

Lastly, it must be remembered that many of the speculations of the preceding part of the century had remained barren, and many investigations had gone astray through lack of knowledge of the minuter changes which lie at the bottom of physiological events. Those minuter changes could not but lay hidden so long as there was no adequate knowledge of minute structure. I have already referred to the improvements of the microscope taking place in the thirties, and this soon bore fruit in the rapid growth of that branch of biologic science once called general anatomy, later on microscopic anatomy, and now best known by the name of histology. It is well-nigh impossible to exaggerate the importance of a histological basis for physiological deductions; it is one of the chief means through which progress has been made and must continue to be made. In the earlier days of physiology the grosser features of structure forming the subject-matter of ordinary anatomy guided the observer to the solution of problems about functions; but after a while these became exhausted, having yielded up all they had to yield, and in due time their place was taken by the finer features disclosed by the microscope. These show as yet no signs of exhaustion, and we may look forward in confidence to their standing us in good stead for years to come. We may expect them to last until we pass, insensibly, from that molecular structure which makes itself known by optical changes to that finer molecular structure which is only revealed by and inferred from its effects, which is an outcome of the ultimate properties of matter, and which is the condition, and so the cause, of all the phenomena of life.

The early forties of the present century may be taken as marking the rapid rise of histological inquiry. It is true that, even before this, the labors of Henle had gone far; that in this country the brilliant Bowman had already (in 1840) given to the world his classic work on the structure of striated muscle, and a little later (1842) his hardly less important work on the structure of the kidney; that the sagacious Sharpey had embodied, in Quain's Anatomy, a whole host of important histological observations, and that many others were at work. Nevertheless, one has only to remember how closely the progress of histology is bound up with the name of Kölliker, and to call to mind that Kölliker's first paper was not published until 1841, to see clearly how much of our present knowledge of histology and all that that brings with it, has been gathered in since Wharton Jones taught it to the young Huxley.

If the gap which parts the physiological learning of that time from the learning of to-day is great, still greater is the gap in the teaching. Though at Charing Cross and in some other schools a course of physiology was given, apart from that of anatomy, this was not separately recognized by the College of Surgeons; it demanded simply a course of anatomy and physiology, of which the lion's share fell undoubtedly to anatomy.

In accordance with this, in most schools, at all events the greater part, and perhaps the sounder part of the physiology taught, was that which may be deduced from anatomical premises. Where the teacher went beyond this, he in most instances at least wandered into academical disquisitions and sterile discussions. Only in rare hands, such as those of Wharton Jones and William Sharpey, was the subject so treated as to be of any real use as a mental training for the medical student preparing his mind to view rightly biological problems. The science was not as yet sufficiently advanced to be an educational engine which could be safely intrusted to the ordinary teacher's use. And the method of teaching it, happily recognized now, which alone insures the salutary influences of the knowledge acquired, that of following out in the laboratory the very steps along which the science has trod, was then wholly unknown. It was as a brilliant favorite pupil that young Huxley was encouraged by Wharton Jones to use the microscope himself, and study, among other things, the structures of hairs; he was not led to it, as one of a flock, in a practical course.

Indeed, one kind of knowledge only was at that time demanded of the medical student, in such quantity and in such a way as to render the study of it a real mental training. Not in one year only of his course, but in each year—in his first, his second, and his third year—was the student, who hoped to obtain the diploma of the college, compelled to attend lectures, each course consisting, not as in other subjects of seventy, but of double that number of lectures, on what was styled anatomy and physiology, but was in the main what we now call anatomy. Moreover, the student learned even then his anatomy in the same way that he is bid to learn all other subjects now, not merely by listening to lectures, or even by witnessing formal demonstrations, but by individual labor in the laboratory—in that laboratory which we call a dissecting room. Nowadays it may seem strange to insist that the student should be studying anatomy during all the three years of his curriculum, down to the very end of his studentship. But we must admit the wisdom of it then. At that time human anatomy was the one branch of knowledge which had achieved anything like complete development, and which successive generations of able teachers had shaped into an engine of mental training of the highest value. It was then the mainstay of medical scientific teaching. It was in the dissecting room that the student, of the time of which we are speaking, acquired the mental attitude which prepared him for the bedside. He

there learned to observe, to describe, to be accurate and exact, and the time spent there was wisely judged to be the most precious of his apprenticeship. The shaping of his mind by help of orderly arranged facts was perhaps even of greater value than the mere acquisition of the facts, important as this might be.

The authorities of the time were, I venture to repeat, in my opinion wiser in their generation in making this well-developed, accurately taught science of anatomy the backbone of the medical student's education; they were wise in making relatively little demand on the student in respect to the other sciences cognate and preparatory to medicine, the value to him of which consisted then chiefly in the facts which they embodied: they were also wise in giving him leave to defer his study of them until his knowledge of something of the needs of his future profession should have opened his eyes to the value of those sciences as mere records of facts.

I also, however, venture to think that the advance of these sciences since then has greatly changed their bearing towards the medical student, no less than towards medicine. What was wisdom in the forefathers is not necessarily wisdom in us the children. I have no wish to take advantage of the occasion of this lecture to make an excursion into the troubled land of medical education. But I feel sure—indeed I know—that I am only saying what the man whose name these lectures bear always felt, and indeed often said, when I suggest for consideration the thought that while some choice out of that advancing flood of science which is surging up around us, and all of which has some bearing on the medical profession, some choice as to what must be known by him who aspires to be the instrument of the cure and prevention of disease is rendered necessary by the struggle for existence—a decided and even narrow choice, lest the ordinary mind be drowned in the waters which it is bid to drink. In making that choice, we should remember that an attitude of mind once gained is a possession for ever, far more precious than the facts which are gathered in with toil, and flee away with ease. This should be our guiding principle in demanding of the medical student knowledge other than that of disease itself.

The usefulness, and so the success, of a doctor is largely dependent on many things which belong to the profession viewed as an art, on quickness of sight, promptness of decision, sleight of hand, charm of manner, and the like—things which can not be taught in any school. But these are in vain unless they rest on a sound and wide knowledge of the nature of disease, on a sound and wide grasp of the science of pathology; and this can be taught. By a sound and wide grasp, I mean such a one as will enable him who has it to distinguish, as it were by insight, among the new things which almost every day brings to him that which is a solid gain from that which is a specious fallacy. Such a grasp is only got by such a study as leads the mind beyond the facts into the very spirit of the science.

But what we call pathology is a branch—a wide and recondite branch, but still a branch of that larger science which we call physiology; it employs the same methods, but applies them to special problems. So much are the two one that it would doubtless be possible to teach pathology to one who knew no physiology; such a one would learn physiology unawares. But at a great waste of time. For physiology, in its narrower sense, being older, has become organized into an engine which can be used for leading the mind quickly and easily into the spirit and methods of true pathological inquiry. The teaching of it as an introduction to pathology is an economy of time. That, I take it, if compulsion be justifiable at all, is the justification of its being a compulsory study.

Further, the methods of physiology, in turn, are the methods of physics and of chemistry, used hand in hand with other methods special to the study of living beings, the general methods of biology. And here again it is an economy of time that the student should learn these methods each in its own science, and this is the justification for making these sciences also compulsory. But in all the regulations which are issued concerning these several ancillary sciences, this surely should be kept in view, that each science should be taught not as a scientific accomplishment of value in itself, but as a stepping stone to professional knowledge, of value because it is the best means of bringing the student on his way to that.

II.

Now let me turn to another theme suggested by what has happened in science and in the profession since the days of Huxley's studentship, and that is the complexity of the bearings of any one discovery, of any one advance, as well on science itself as on the applications of science.

In the garment of science, with which man is wrapping himself round, or rather is being wrapped round, the several threads are woven into an intricate web. As the loom which is weaving that ever-spreading garment takes in new warp and new woof, such threads only of each are taken in as can be fitly joined to those which have come in before; each thread as it is twisted in becomes a hold for other threads to be caught up later on. No single observation, no single experiment stands alone by itself, nor can its worth be rightly judged by itself alone. The mistaken philanthropists who have put restrictions, and would put more on physiological investigations, betray that ignorance of the ways of science, which seems to be a necessary condition of their attitude, when they ask us to state in a sentence the direct application to the good of man of each experiment on a living animal. In the doors of science, each the opening as often of a path as of a chamber, it is not, as such folk seem to think, that each bobbin pulls only one latch. Every experiment, every observation has, besides its immediate result, effects which, in proportion to its value, spread away on all sides

into even distant parts of knowledge. The good of the experiment by itself is soon merged in the general good of scientific inquiry. The science of physiology, and by implication the art of medicine, is built up in part on experiments on living animals; in part only, but that part is so woven into all the rest that any attempt to draw it out would lead to a collapse of the whole.

It is because each experiment or observation is thus a thread caught up in a close-set web, that its value depends not alone on the mere result of the experiment or observation itself, but also, and even more so, on the time at which, and on the circumstances and relations under which it is made. This truth the real worker in science has borne in upon him again and again; it is this which leads him to that humility which has ever been the outward token of the fruitful laborer. He feels that it is not so much himself working for science as science working through him.

Let me attempt to illustrate this by dwelling on some two or three single observations in physiology, made almost at the time or very soon after the time at which Huxley was a student. It will, I think, be seen that each of them has reached a long way in its bearing on the science of physiology and on the art of medicine; that the full effect of each has been dependent both on what went before and on what has happened since, and though they were all made, so to speak, long ago some of their fruits were brought in as it were yesterday, and their full fruition is perhaps not yet accomplished.

I will first invite your attention to a single experiment, for, though repeated on various animals, we may call it a single experiment, which in the fall of the year 1845 Ernest Heinrich Weber, then professor of anatomy at Leipzig, and his brother Eduard Friedrich, reported to an assembly of Italian scientific men in Naples, and of which they subsequently published an account in Müller's Archiv in 1846. Making use of the recently introduced rotating electro-magnetic apparatus (the physical discovery begetting the physiological one), they found that powerful stimulation of the vagus nerves had the unexpected result of stopping the heart from beating.

This single experiment, which I may quote by the way as a typical experiment on a living animal—for it is impossible to imagine how the discovery of this action of the vagus on the heart could have been made otherwise than by an experiment on a living animal—this single experiment has made itself felt far and wide throughout almost the whole of physiology.

In the first place, it has made us understand in a way impossible before the experiment how, through the intervention of the nervous system, the work of the heart is tempered to meet the strain of varying circumstances. As I said a little while back, only a few years before even eminent observers were groping about in a dim light, hotly discussing whether the brain and spinal cord could affect the beat of the

heart. To all these discussions Weber's experiment came as a great light in a dark place.

There is no need for me to insist how this knowledge that impulses descending the vagus slow or restrain the heart beat, and the knowledge genetically dependent on this, that impulses reaching the heart along the cardiac sympathetic nerves from the thoracic spinal cord stir up the heart to more vigorous or frequent beats, have since served as a guide for the physician in the intricate problems of cardiac disease, and that with increasing security as our knowledge of the details of the actions has increased. The knowledge may not always have been wisely used. On this point perhaps I may be allowed to repeat the caution which I may have given elsewhere concerning the dangers of taking a new physiological fact direct and straight, raw and bleeding, as it were, from the laboratory to the bedside. The wise physiologist takes care, even in physiology itself, not to use a new fact as an explanation of old problems without a due testing and a direct verification of its applicability. How much more is it needful that the doctor who sails not on the calm seas of the phenomena of health, but amid the troubled tempests which we call disease, should not hastily and heedlessly rush to make practical use of a new fact, tempting as the use may be, until he also has tested its applicability by that clinical study which is his only sure guide. But this is by the way.

In the second place, as a mere method Weber's discovery has in physiological experimentation borne most important fruit. Before Weber's experiment many an investigation, not only on the vascular system itself, but in many other branches of physiology, came to a standstill or went astray because the experimenter had not the means on the one hand to stop or slacken, or on the other to quicken and stir up the heart without interfering largely with the object of his research. Thanks to Weber's experiment and what has come out of it, that can now be done with ease, and thus solutions have been obtained of problems which otherwise seemed insoluble.

In the third place, the experiment has had a profound and widespread influence by serving to introduce a new idea, that idea which we now denote by the word inhibition. Before the experiment, though men's minds were gradually getting clearer concerning the nature of a nervous impulse, all known instances of the action of a nervous impulse had for the result an expenditure of energy; and it was a still open though hotly debated question whether in such actions as when a muscle was thrown into contraction by a nervous impulse this feature of expenditure was not impressed on the muscle by the very nature of the impulse itself. That question the experiment answered in the negative once and for all. Whatever the exact nature of a nervous impulse, it was evidently of such a kind that it might on occasion check expenditure and bank up energy in an increased potential store. Observation soon showed that the heart and vagus was no solitary example. It was

recognized that the due regulation of many of, if not all, the so-called nervous centers was secured not merely by the intrinsic forces of passive rest making themselves felt in the absence of stimulation, but also, and even more so, by the alternating play of antagonistic influences. Throughout all the sciences the resolving a stability seemingly due to intrinsic causes into an equilibrium arising out of the balance of opposing forces has again and again marked a step forward; and it is perhaps not too much to say that a like analysis, prompted by the story of the vagus and the heart, has profoundly modified all our conceptions of the way in which nervous impulses, sweeping along the intricate yet ordered network of paths in the brain and spinal cord, determine the conduct of life. The idea has of course been abused as well as used, as what idea has not? Such a word as inhibition could not but fail to have a blessed sound in the ears of the ignorant; the idea has been ignorantly and wrongly applied; but this is of little moment in view of the help which it has given to wise and well-directed inquiry.

And the idea has spread with fruitful results beyond the limits of nervous impulses; it has been carried deep down into the very innermost molecular processes of life. The closer we penetrate into the physical-chemical events through which living matter grows, lives, and dies, the clearer does it seem that life itself is a shifting outcome of two opposing sets of changes—one synthetic, constructive, the other destructive, analytic—and that the key to this and that riddle of vital action lies within the grasp of him who can clearly lay hold of the mutual relations of these conflicting changes. The story of the vagus and the heart is a tale, not of the heart alone, not of the nervous system alone, but of all living matter. The light which first shone in the experiment of the brothers Weber may, in a sense, be said to have gone out into all the lands of physiology.

Let me now turn your attention to an experiment made a few years later. This is also an experiment made on a living animal, and whatever good may have come out of that to which it has given rise must be reckoned as the fruit of an experiment.

In 1851 Claude Bernard made known that division of the cervical sympathetic led to a widening of the blood vessels and a warming of the ear and other parts of the head and neck. This was the beginning of what may rightly be called the great vaso-motor knowledge. It may be true that more than a hundred years before, in 1727, Du Petit had observed much the same thing, but nothing came out of it; the germinal time had not yet arrived. It may be true that other observers since Du Petit had divided the cervical sympathetic and noted the effects; but these had their attention directed chiefly to changes in the pupil. It may be true that Brown-Séquard and Waller a few months before Bernard himself was able to do so supplied the complement to the original experiment by showing that stimulation of the peripheral part of the divided sympathetic constricted the blood vessels and reduced the

temperature. All this may be true, but there remains the fact that with Bernard's experiment the new light began; that experiment marks the beginning of our vaso-motor knowledge.

I have already spoken of the prolonged discussions which, just before the date of Huxley's studentship, were taking place touching the question whether or no the blood vessels were muscular and contractile. That question had, meanwhile, been definitely settled by Henle's demonstration, in 1840, that the tissue in the middle coats of arteries really consisted in part of muscular tissue of the kind known henceforward as plain muscular tissue. But for some years no use was made of this discovery in the direction of explaining the intervention of the nervous system in the government of the circulation. That began with Bernard's experiment.

It would, I venture to think, be sheer waste of your time and mine, if I were to attempt to labor the theme of the large share in our total physiological knowledge which is now taken up by the vaso-motor system and all that belongs to it, and of the extent to which the physiology of that system has woven itself into pathological doctrines, and helped medical practice. I would simply ask the lecturer on physiology in what stress he would find himself if he were forbidden in his teaching to say a word which would imply that the caliber of the blood vessels was influenced by the contraction of their walls through nervous influence; or ask the student how often, in an examination of to-day, he would have to sit seeking inspiration by biting his pen, or staring at the roof, if he too, in his answers, could never refer to vaso-motor actions. Whatever part of physiology we touch, be it the work done by a muscle, be it the various kinds of secretive labor, be it that maintenance of bodily temperature which is a condition of bodily activity, be it the keeping of the brain's well-being in the midst of the hydrostatic vicissitudes to which daily life subjects it—in all these, as in many others, we find vaso-motor factors intervening; and, to say nothing of the share taken by these in the great general pathological conditions of inflammation and fever, they also have to be taken account of by the doctor in studying the disordered physiological processes which constitute disease, whatever be the tissue affected by the morbid conditions. Take away from the physiological and pathological doctrines of to-day all that is meant by the word vaso-motor, and those doctrines would be left for the most part, a muddled, unintelligible mass. To so great an extent as that which Bernard's experiment began entered into our modern views.

It was Bernard's good fortune, but deserved good fortune, to announce, almost at the same time, two fundamental discoveries. For I venture to claim for his discovery of the formation of glycogen in the liver, briefly indicated in 1850, more fully expounded in 1851, an importance only second, if second, to that of the experiment with which we have just been dealing.

To judge of its importance we must look at it from more than one point of view.

At the time when Huxley was sitting at the feet of Wharton Jones, the teaching of the schools was largely governed by the view that the animal organism, in contradistinction to the vegetable organism, was essentially destructive in its chemical actions, possessing no power in itself of synthetic construction. It is true that the possible synthesis of organic compounds special to the animal body had long before, in 1828, been shown by Wöhler's artificial formation of urea. It is true also that Huber, in the case of bees, and Liebig, in the case of cows, had already shown that wax and fat must be in part manufactured out of something that was not fat. The conclusions, however, of these observers were at best somewhat distant inferences from statistical data; and, in any case, had not as yet made much way in the direction of general acceptance. But Bernard's experiment was in the form of an ocular demonstration. The glycogen which had been formed in the liver could be extracted, could be seen, handled, and, if need be, tasted, a result adequate to convince even a physiological Thomas. We may claim for Bernard's glycogen discovery, that, as the first realistic proof of the synthetic powers of the animal organism it did much to establish a truth, which succeeding observations have only served to confirm and extend, namely, that the animal, no less than the vegetable organism, possesses synthetic powers, and that the want of prominence of these in the ordinary work of the animal body is to be attributed to economic reasons, and not to absence, or even scantiness of power.

But there is another aspect from which the discovery must be viewed. At the time of which we are speaking, physiologists were still, as they had been of old, largely under the influence of a somewhat mechanical conception of the body as a collection of organs, each of which had its special use or function, the unity of the body being maintained by the mutual adaptation of the constituent organs. This was further developed into the view that when a use of an organ had been satisfactorily made out, when a function had been made clear, all that remained to be done, in the way of research, was simply to inquire how far and in what ways the performance of that function was influenced by changes in the rest of the body, or by external circumstances. It was acknowledged, for instance, on all hands that the function of the liver was to secrete bile, and physiologists in general were content to look forward for future discoveries which should throw light on the exact nature of the mechanism of the secretion, and on why the liver secreted now more, now less bile, and to these alone without expecting anything else.

Bernard's discovery that the liver not only secreted bile but manufactured glycogen fell on physiologists like a bolt from the blue. The knowledge that the same hepatic cell was engaged both in secreting bile and manufacturing glycogen, and that the sugar or other prod-

ucts of digestion were carried from the intestine, not straight to the tissues which they were destined in any case ultimately to nourish, but to the liver, there to undergo transformation and await some future fate, marked the beginning of a new way of looking at the problems of nutrition. It was recognized that these became less simple—more complex than they had formerly seemed; but the very complexity gave hope of possible solutions. It was seen that as the blood swept in the blood stream through the several tissues it might undergo profound changes without any visible outward token, such as that of the appearance of secretion in the duct of a gland or of the contraction of a muscle—might undergo changes which could only be demonstrated by differences in the composition or properties of the blood as it came to or left this or that tissue. The technical difficulties of the analysis of blood prevented any immediate marked steps in the way of advance, and attempts to establish in respect to any particular tissue the changes which the blood underwent in it, by inference from the results of experimental interference, met with difficulties of another but no less serious kind. Hence the world had to wait some little time before the new idea which Bernard's discovery had started bore important or striking fruit. Yet it was not very long before it was seen that the hepatic cell had heavy duties touching the metabolic changes of proteid as well as a carbohydrate material; that it, and not the kidney alone, had to do with urea as well as sugar, and the difficulties, which physiologists in the early half of this century must have keenly felt—how to reconcile the bald task of secreting bile, which alone technical physiology alloted to the liver, with the overweening importance which not only popular experience, but more exact clinical study, could not but attach to that organ—began to steal away. A little later on exact experimental inquiry converted into certainty the suspicions which clinical study had raised, that the blood in streaming through the thyroid gland underwent changes of supreme importance to the nutrition of the tissues of the body at large. Still, a little later, the Bernardian idea, if I may so venture to call it, doubling, so to speak, on itself, led to the discovery that the mysteries of the fate of sugar in the body were not lodged in the liver alone, but might be traced to the pancreas. It was seen that as the blood streaming through the liver worked on sugar besides secreting bile, so the pancreas, besides secreting its marvellous omnipotent juice, also influenced, though in a different way, the career of sugar in the body; that the disease we call diabetes was or might be in some way connected with the pancreas no less than with the liver. I need not go on to speak of recent researches on the suprarenal capsules or of other organs. It is enough to note that one of the most promising lines of inquiry at the present day is that relating to the changes of which I am speaking, sometimes known under the name of "internal secretion." Every year—nay, almost every month—brings up some new light as to the details of the great

chemical fight which the blood is carrying on in all the tissues of the body. It may be perhaps to-morrow that we shall learn of some work of a kind wholly unexpected which is carried out by that great Malpighian layer of the skin which wraps round our whole frame. In any case, the line of inquiry is one of the most fruitful of those of the present day. I may add, too, I think, that it is one which has been of the greatest direct use to mankind, and promises still more. It is true that Bernard's discovery of glycogen, and perhaps especially the diabetic puncture, raised hopes which have not been fulfilled. Not to-day, any more than forty years ago, is it in our power wholly to remove the disease which we call diabetes. But short of complete mastery, how great is our power now compared with then. And when we remember that the pancreatic relations of sugar are far from being worked out, and that such knowledge as physiologists already possess has not yet made much way in clinical study, we may look forward to marked progress possibly in no very distant time.

Further, if there be any truth in what I have insisted upon—that the value of a discovery is to be measured not only by its immediate application, theoretical and practical, but also by the worth of the idea which it embodies and to which it gives life; and if it be true, as I have suggested, that by the genesis of ideas the discovery of glycogen is mother of all our knowledge of internal secretion, in its widest sense, of the work of the thyroid and other like bodies, then the good to suffering mankind which may be laid to the door of Bernard's initial experiment is great indeed.

The next result to which I will call your attention is again an experiment, and once more an experiment on a living animal. In 1850 Augustus Waller described in the Philosophical Transactions the histological changes which division of the hypoglossal and glossopharyngeal nerves in the frog produced in the fibers of the distal portions of the nerves, and shortly afterwards developed this initial result into the more general view of the dependence of the nutrition of a nerve fiber on its continuity with a cell in the central nervous system, or in the case of afferent fibers, in the ganglion of the posterior root.

This discovery was at the time and has since continued to be of value as a contribution to physiological ideas. It had its share in promoting the progress—which, though slight, is still a progress—of our understanding the obscure influences which the part of a cell inclosing the mysterious nucleus exercises over all the rest of the cell, and perhaps even to-day the theoretical value of that degeneration of nerve fibers the knowledge of which we owe to Waller is not adequately appreciated and the lead which it gives not followed out as it might be. In spite of all we know, we are much too apt to fall back on the conception that when no nervous impulse is traveling along a nerve fiber the nerve fiber is in a state of motionless quiescence, and that a nervous impulse, when it does come, sweeps over the fiber as a

wave sweeps over a placid lake; but the Wallerian degeneration gives such a view the lie direct. When we reflect that the finely balanced molecular condition, which itself is nothing more than the falsely seeming quiescence of an equilibrium of opposing motions in the ultimate fibrils of the nerve twigs in the ultimate phalanx of the finger, by which we touch and get to know the world without us, is dependent on what is going on around the nucleus of a cell or the nuclei of some cells in the ganglion or ganglia of certain upper spinal nerves, so that if the continuity of the axis cylinder process be anywhere broken the figure of the molecular dance changes at once and riot takes the place of order. When we reflect on this it is clear, I say, that between the molecules of the ultimate fibrils branching in the Malpighian layer of the ball of the finger and the molecules within the immediate grasp of the nucleus of the cell from which those fibrils start there must be ever-passing thrills—thrills, it is true, of so gentle a kind that no physical instrument we as yet possess can give us warning of them, so gentle that compared with them the wave which carries what we call a nervous impulse must appear a roaring avalanche, but still thrills the token of continued movement; and of such gentle, impalpable, unnoticed thrills we must in the future take full account if we are ever to sound the real depth of nervous actions.

It is not, however, as a contribution to theoretical conceptions, but rather as a method, that the results of Waller have so far had their chief effect on the progress of physiology and medicine, and I have chosen it as a thing to dwell on because it seems to me a striking instance of the value of a method merely judged as a method, and, further, because the value of its use illustrates my theme, that the success of any one scientific effort is contingent on the converging aid of other efforts. For some time, it is true—for years, in fact—the Wallerian method was employed solely or chiefly in what, without reproach, may be called the smaller problems of physiology. It settled many topographical questions. It cleared our views as to the distribution of afferent and efferent fibers. It seemed to add or replace a few stones here and there in the growing building, but it did not greatly change the whole edifice. After a while, however, it met with two helpmates—the one sooner, the other later—and, by means of the three together we have gained and are still gaining such additions to our knowledge of the ways in which the central nervous system works out the acts which make up our real life as to constitute perhaps the most striking progress in the physiology of our time. A wholly new chapter of nervous physiology has through them been opened up.

The one colleague is to be found in the experiments of Fritz and Hitzig; and of Ferrier, again, experiments on living animals—experiments which, by demonstrating the existence of definite paths for the play of nervous impulses within the central nervous system, opened up paths for the play of new ideas concerning the working of that system.

I say "demonstrating the existence of definite paths," for this, and not the topographical recognition of so many centers of hypothetical nature, is the solid outcome of experiments on local stimulation of the cerebral cortex. Views come and go as to what is happening when the current is flitting to and fro between two electrodes placed on a particular spot of the Rolandic area. The solid ground on which each view strives to establish itself is that the particular spot is joined by definite nervous paths to particular peripheral parts. I say "demonstrating the existence of particular paths," but what would have been the demonstrative value of the experiments of stimulation or of removal by themselves without the anatomical support furnished by the Wallerian method? And I may justly include within the Wallerian method not the mere tracking out the degenerated fiber by the simple means at Waller's own disposal, but such finer, surer search as is afforded by the later help given by the newer development of the staining technique.

They who have the widest experience of experiments on living animals are the first to own that in a region of delicate complexity like that of the central nervous system the interpretation of the results of any experimental interference may be, and generally is, in the absence of aid from other sources, a matter of extremest difficulty, one in which the observer, trusting to the experiment alone, may easily be led astray. I need not labor the question what would have been the value of the mere effects of stimulating or even of removal of parts of the cerebral cortex, and whither would they have led us, had the experimental results not been supported and their interpretation guided by the teachings of the Wallerian method. It is not too much to say that the experiments of Ferrier and his peers, brilliant as they were, might have remained barren, useful only as isolated bits of knowledge, or might even have led us astray, had they not been complemented by anatomical facts. They have not remained barren and they have not led us astray. The Wallerian method picked out from the tangle of nerve fibers making up the white matter of the brain and spinal cord the pyramidal tract running from the Rolandic area to the origins of all the motor roots, even of the lowest, and so, joining hands with the experiment, made it clear that, whatever might be the exact nature of the events taking place in a particular spot of the cortex of that area, that spot was, by the definite paths of particular nerve fibers, put in connection with definite skeletal muscles. The pyramidal tract was further shown to be merely one—an important one, it is true, but still merely one—of a large class. So it is that the experimental results and the Wallerian results, not merely in that Rolandic area where the results of experiment take on the grosser form of readily appreciated interference with movements, but in other regions where other finer, more occult manifestations of nervous and psychical actions have to be dealt with, are, it may be slowly, but yet surely, resolving that which seemed to be a hopeless tangle of interweaving and interlacing nerve fibers

and cells into an orderly arrangement, of which the key is seen to be that each nerve filament is a path of impulses coming from some spot—it may be from near, it may be from afar—where events are taking place, and carrying the issue of those events to some other spot, there to give rise to events having some other issue.

But a third factor was wanting to forward our insight into this orderly arrangement, and especially by again affording an anatomical basis to open the way toward explaining what was the order of events in the spots or centers, as we call them, in which the filaments began or ended, and what was the mechanism of the change of events. This, I venture to think, we may find in the special histological method which, however much its usefulness, has been enhanced by its subsequent development in the hands of Cayal, Kölliker, and others, as well as by the coincident methyl-blue method we owe to Golgi. The final word has not yet been said as to the exact meaning and value of the black silver pictures which that method places before us; but this, at least, may be asserted that by means of them the progress of our knowledge of the histological constitution of the central nervous system has within the last few years made strides of a most remarkable kind. It may be that those pictures are in some of their features misleading, it may be that the terminal arborization, and their lack of continuity with the material of the structures which they grasp, does not afford an adequate explanation of the change in the nature of the nervous impulses which takes place at the relays of which the arborizations seem the token; it may be, indeed it is probable, that we have yet much to learn on these points. But notwithstanding this it must still be said that, by the help of this method, our knowledge of how the fibers run, where they begin and where they end within the brain and spinal cord has advanced, and is advancing in a manner which, to one who looks back to the days when Huxley was studying within these walls, seems little short of marvelous.

Let me once more repeat, the value of this silver method is not an intrinsic one; it has its worth because it fits in with other methods; it is available on account of what is known apart from it. I imagine that if in 1842 Huxley, at Wharton Jones's suggestion, had invented the silver method it would have remained unknown and unused. The time for it had not then come. The full fruition which it has borne and is bearing in our day has come to it because it works hand in hand with the two other methods of which I have spoken—the Wallerian and the experimental methods.

It is these three working together which have brought forth what I may venture to call the wonders which we have seen in our days, and I can not but think that what we have seen is but an earnest of that which is to come. In no branch of physiology is the outlook more promising, even in the immediate future, than in that of the central nervous system. But surely I do it wrong to call it merely a branch

of physiology. It is true that if we judge it by even the advanced knowledge of to-day, it takes up but a small part of the whole teaching of the science; but when we come to know about it that which we are to know, all the rest of physiology will shrink into a mere appendage of it, and the teacher of the future will hurry over all that to which to-day we devote so much of the year's course, in order that he may enter into the real and dominant part.

There is no need for me to expound in detail how the knowledge gained by the three methods of which I have been speaking, in laying bare the secrets of nervous diseases and opening up the way for successful treatment and accurate and trustworthy prognosis, has helped onward the art of medicine. Even the younger among us must be impressed when he compares what we know to-day of the diseases of the nervous system with what we knew, I will not say fifty, but even twenty, nay even ten, years ago. Do not for a moment suppose that I am attempting to maintain that the great clinical progress which has taken place has resulted from the direct, immediate application to the bedside of laboratory work, or that I wish to use this to exalt the physiological horn. I would desire to take a higher and broader standpoint, namely this, that the close relations and mutual interdependence of laboratory physiology and that bedside physiology which we sometimes call pathology, and the necessity of both for the medical art, are nowhere more clearly shown than by the history of our recent advance in a knowledge of the nervous system as a whole. In this, when we strive to follow out the genesis of the new truths, it is almost impossible to trace out that which has come from the laboratory and that from the hospital ward, so closely have the two worked together; an idea started at the bedside has again and again been extended, shaped, or corrected by experimental results and been brought back in increased fruitfulness to the bedside. On the other hand, a new observation which, had it been confined to the laboratory, would have remained barren and without result, has no less often proved in the hands of the physician the key to clinical problems the unlocking of which has in turn opened up new physiological ideas.

And, though the scope of these Huxley lectures is to deal with the relations of the sciences to the medical art, I shall, I trust, be pardoned if I turn aside to point out that this swelling knowledge of how nerve cell and nerve fiber play their parts in bringing about the complex work done by man's nervous system is not narrowed to the relief of those sufferings which come to humanity in the sick room. Mankind suffers much more deeply, much more widely, through misdirected activities of the nervous system, the meddling with which lies outside the immediate calling of the doctor. Yet every doctor, I may say every thoughtful man, can not but recognize that the distinction between a so-called physical and a so-called moral cause is often a shadowy and indistinct one, and that certainly so-called moral results are often the

outcome, more or less direct, of so-called physical events. I venture to say that he who realizes how strong a grip the physiologist and the physician, working hand in hand, are laying on the secret workings of the nervous system, who realizes how, step by step, the two are seeing their way to understand the chain of events issuing in that sheaf of nervous impulses which is the instrument of what we call a voluntary act, must have hopes that that knowledge will ere long give man power over the issue of those impulses, to an extent of which we have at present no idea. Not the mere mending of a broken brain, but the education, development, and guidance of cerebral powers, by the light of a knowledge of cerebral processes, is the office in the—we hope—not far future of the physiology of the times to come.

I might bring before you other illustrations of the theme which I have in hand. I could, I think, show you that the very greatest of all recent advances in our art, that based on our knowledge of the ways and works of minute organisms, has come about because several independent gains of science met, in the fullness of time, and linked themselves together. But my time is spent.

I should be very loth, however, and you, I am sure, would not wish that I should end this first Huxley lecture without some word as to what the great man whose name the lectures bear had to do with the progress on some points of which I have touched. He had an influence, I think a very great one, upon that progress, though his influence, as is natural, bore most on the progress in this country.

The condition and prospects of physiology in Great Britain at the present moment are, I venture to think, save and except the needless bonds which the legislature has placed upon it, better and brighter than they ever have been before. At one time, perhaps, it might have been said that physiology was for the most part being made in Germany; for, in spite of the fact that some of the greatest and most pregnant ideas in physiology have sprung from the English brain, it must be confessed that in the more ordinary researches the output in England has at times not been commensurate with her activities of other kinds. But that cannot be said now. The English physiological work of to-day is, both in quantity and quality, at least equal to that of other nations, having respect to English resources and opportunities. Part of this is probably due to that activity which is the natural response to the stimulus of obstacles. The whip of the antivivisectionists has defeated its own end. But it is also in part due to the influence of Huxley.

That influence was twofold, direct and indirect. I need not remind you that not only when he sat on the benches of Charing Cross Hospital, but all his lifelong afterwards, Huxley was at heart a physiologist. Physiology, the beauty of which Wharton Jones made known to him, was his first love. That morphology, which circumstances led him to espouse, was but a second love: and though his affection for it grew

with long-continued daily communion, and he proved a faithful husband, devoting himself with steadfast energy to her to whom he had been joined, his heart went back again, and especially in the early days, to the love which was not to be his. What he did for morphology may perhaps give us a measure of what he might have done for physiology had his early hopes been realized. As it was, he could show his leanings chiefly by helping those who were following the career denied to himself. Unable to put his own hand to the plow, he was ever ready to help others whom fate had brought to that plow, especially us younger ones, to keep the furrow straight. And if I venture to say that the little which he who is now speaking to you has been able to do is chiefly the result of Huxley's influence and help, it is because that only illustrates what he was doing at many times and in many ways.

His indirect influence was perhaps greater even than his direct.

The man of science, conscious of his own strength, or rather of the strength of that of which he is the instrument, is too often apt to underrate the weight and importance of public opinion, of that which the world at large thinks of his work and ways. Huxley, who had in him the making of a sagacious statesman, never fell into this mistake. Though he felt as keenly as any one the worthlessness of popular judgment upon the value of any one scientific achievement, or as to the right or wrong of any one scientific utterance, he recognized the importance of securing toward science and scientific efforts in general a right attitude of that popular opinion which is, after all, the ultimate appeal in all mundane affairs.

And much of his activity was directed to this end. The time which seemed to some wasted, he looked upon as well spent, when it was used for the purpose of making the people at large understand the worth and reach of science. No part of science did he more constantly and fervently preach to the common folk, than that part which we call physiology. His little work on physiology was written with this view, among others, that by helping to spread a sound knowledge of what physiology was, among the young of all classes, he was preparing the way for a just appreciation among the public of what were the aims of physiology, and how necessary was the due encouragement of it.

And if, as I believe to be the case, physiology stands far higher in public opinion, and if its just ambitions are more clearly appreciated than they were fifty years ago, that is in large measure due to Huxley's words and acts. I have not forgotten that he was one of a commission whose labors issued in the forging of those chains to which I have referred; but knowing something of commissions, and bearing in mind what were the views of men of high influence and position at that time, I tremble to think of what might have been the fate of physiology if a wise hand had not made the best of adverse things.

One aspect of Huxley's relations to science deserves, perhaps, special comment. On nothing did he insist, perhaps, more strongly than on

the conception that great as are the material benefits which accrue from science, greater still is the intellectual and moral good which it brings to man; and part of his zeal for physiology was based on the conviction that great as is the help which, as the basis of the knowledge of disease, and its applications to the healing art, it offers to suffering humanity in its pains and ills, still greater is the promise which it gives of clearing up the dark problems of human nature, and laying down rules for human conduct. No token, in these present days, is more striking or more mournful than that note of pessimism which is sounded by so many men of letters, in our own land, no less than in others, who, knowing nothing of, take no heed of the ways and aims of science. Cast adrift from old moorings, such men toss about in darkness on the waves of despair. There was no such note from Huxley. He had marked the limits of human knowledge, and had been led to doubt things about which other men are sure, but he never doubted in the worth and growing power of science, and, with a justified optimism, looked forward with confident hope to its being man's help and guide in the days to come.

LUDWIG AND MODERN PHYSIOLOGY.[1]

By J. Burdon-Sanderson.

I. INTRODUCTION.

The death of any discoverer—of anyone who has added largely to the sum of human knowledge—affords a reason for inquiring what his work was and how he accomplished it. This inquiry has interest even when the work has been completed in a few years, and has been limited to a single line of investigation—much more when the life has been associated with the origin and development of a new science and has extended over half a century.

The science of physiology, as we know it, came into existence fifty years ago, with the beginning of the active life of Ludwig, in the same sense that the other great branch of biology, the science of living beings (ontology), as we now know it, came into existence with the appearance of the "Origin of Species." In the order of time physiology had the advantage, for the new physiology was accepted some ten years before the Darwinian epoch. Notwithstanding, the content of the science is relatively so unfamiliar, that before entering on the discussion of the life and work of the man who, as I shall endeavor to show, had a larger share in founding it than any of his contemporaries, it is necessary to define its limits and its relations to other branches of knowledge.

The word physiology has in modern times changed its meaning. It once comprehended the whole knowledge of nature. Now it is the name for one of the two divisions of the science of life. In the progress of investigation the study of that science has inevitably divided itself into two: ontology, the science of living beings; physiology, the science of living processes, and thus, inasmuch as life consists in processes, of life itself. Both strive to understand the complicated relations and endless varieties which present themselves in living nature, but by different methods. Both refer to general principles, but they are of a different nature.

To the ontologist, the student of living beings, plants, or animals, the great fact of evolution, namely, that from the simplest beginning our own organism, no less than that of every animal and plant with its

[1] Founded upon a lecture delivered at the Royal Institution, January 24, 1896. Printed in Science Progress, Vol. V, No. 25, 1896, pages 1–21.

infinite complication of parts and powers, unfolds the plan of its existence—taken with the observation that that small beginning was, in all excepting the lowest forms, itself derived from two parents, equally from each—is the basis from which his study and knowledge of the world of living beings takes its departure. For on these two facts—evolution and descent—the explorer of the forms, distribution, and habits of animals and plants has, since the Darwinian epoch, relied with an ever-increasing certainty, and has found in them the explanation of every phenomenon, the solution of every problem relating to the subject of his inquiry. Nor could he wish for a more secure basis. Whatever doubts or misgivings exist in the minds of "nonbiologists" in relation to it may be attributed partly to the association with the doctrine of evolution of questions which the true naturalist regards as transcendental, partly to the perversion or weakening of meaning which the term has suffered in consequence of its introduction into the language of common life, and particularly to the habit of applying it to any kind of progress or improvement, anything which from small beginnings gradually increases. But, provided that we limit the term to its original sense—the evolution of a living being from its germ by a continuous, not a gradual process—there is no conception which is more free from doubt either as to its meaning or reality. It is inseparable from that of life itself, which is but the unfolding of a predestined harmony, of a prearranged consensus and synergy of parts.

The other branch of biology, that with which Ludwig's name is associated, deals with the same facts in a different way. While ontology regards animals and plants as individuals and in relation to other individuals, physiology considers the processes themselves of which life is a complex. This is the most obvious distinction, but it is subordinate to the fundamental one, namely, that while ontology has for its basis laws which are in force only in its own province, those of evolution, descent, and adaptation, we physiologists, while accepting these as true, found nothing upon them, using them only for euristic purposes, i. e., as guides to discovery, not for the purpose of explanation. Purposive adaptation, for example, serves as a clue, by which we are constantly guided in our exploration of the tangled labyrinth of vital processes. But when it becomes our business to explain these processes—to say how they are brought about—we refer them not to biological principles of any kind, but to the universal laws of nature. Hence it happens that with reference to each of these processes, our inquiry is rather how it occurs than why it occurs.

It has been well said that the natural sciences are the children of necessity. Just as the other natural sciences owed their origin to the necessity of acquiring that control over the forces of nature without which life would scarcely be worth living, so physiology arose out of human suffering and the necessity of relieving it. It sprang, indeed, out of pathology. It was suffering that led us to know, as regards our

own bodies, that we had internal as well as external organs, and probably one of the first generalizations which arose out of this knowledge was, that "if one member suffer all the members suffer with it"—that all work together for the good of the whole. In earlier times the good which was thus indicated was associated in men's minds with human welfare exclusively. But it was eventually seen that nature has no less consideration for the welfare of those of her products which to us seem hideous or mischievous, than for those which we regard as most useful to man or most deserving of his admiration. It thus became apparent that the good in question could not be human exclusively, but as regards each animal its own good—and that in the organized world the existence and life of every species is brought into subordination to one purpose—its own success in the struggle for existence.[1]

From what has preceded it may be readily understood that in physiology adaptation takes a more prominent place than evolution or descent. In the prescientific period adaptation was everything. The observation that any structure or arrangement exhibited marks of adaptation to a useful purpose was accepted, not merely as a guide in research, but as a full and final explanation. Of an organism or organ which perfectly fulfilled in its structure and working the end of its existence nothing further is required to be said or known. Physiologists of the present day recognize as fully as their predecessors that perfection of contrivance which displays itself in all living structures the more exquisitely the more minutely they are examined. No one, for example, has written more emphatically uonp this point than did Ludwig. In one of his discourses, after showing how nature exceeds the highest standard of human attainment—how she fashions, as it were, out of nothing and without tools instruments of a perfection which the human artificer can not reach, though provided with every suitable material—wood, brass, glass, india rubber—he gives the organ of sight as a signal example, referring among its other perfections to the rapidity with which the eye can be fixed on numerous objects in succession and the instantaneous and unconscious estimates which we are able to form of the distances of objects, each estimate involving a process of arithmetic which no calculating machine could effect in the time.[2] In another

[1]I am aware that in thus stating the relation between adaptation and the struggle for existence, I may seem to be reversing the order followed by Mr. Darwin, inasmuch as he regarded the survival of organisms which are fittest for their place in nature, and of parts which are fittest for their place in the organism, as the agency by which adaptedness is brought about. However this may be expressed it can not be doubted that fitness is an essential of organisms. Living beings are the only things in nature which by virtue of evolution and descent are able to adapt themselves to their surroundings. It is therefore only so far as organism (with all its attributes) is presupposed, that the dependence of adaptation on survival is intelligible.

[2]I summarize here from a very interesting lecture entitled "Leid und Freude in der Naturforschung," published in the Gartenlaube (Nos. 22 and 23) in 1870.

discourse—that given at Leipzig when he entered on his professorship in 1865—he remarks that when in our researches into the finer mechanism of an organ we at last come to understand it, we are humbled by the recognition "that the human inventor is but a blunderer as compared with the unknown Master of the animal creation."[1]

Some readers will perhaps remember how one of the most brilliant of philosophical writers, in a discourse to the British Association delivered a quarter of a century ago, averred on the authority of a great physiologist that the eye, regarded as an optical instrument, was so inferior a production that if it were the work of a mechanician it would be unsalable. Without criticising or endeavoring to explain this paradox, I may refer to it as having given the countenance of a distinguished name to a misconception which I know exists in the minds of many persons, to the effect that the scientific physiologist is more or less blind to the evidence of design in creation. On the contrary, the view taken by Ludwig, as expressed in the words I have quoted, is that of all physiologists. The disuse of the teleological expressions which were formerly current does not imply that the indications of contrivance are less appreciated, for, on the contrary, we regard them as more characteristic of organism as it presents itself to our observation than any other of its endowments. But, if I may be permitted to repeat what has been already said, we use the evidences of adaptation differently. We found no explanation on this or any other biological principle, but refer all the phenomena by which these manifest themselves to the simpler and more certain physical laws of the universe.

Why must we take this position? First, because it is a general rule in investigations of all kinds to explain the more complex by the more simple. The material universe is manifestly divided into two parts, the living and the nonliving. We may, if we like, take the living as our Norma, and say to the physicist: "You must come to us for laws; you must account for the play of energies in universal nature by referring them to evolution, descent, adaptation." Or we may take these words as true expressions of the mutual relations between the phenomena and processes peculiar to living beings, using for the explanation of the processes themselves the same methods which we should employ if we were engaged in the investigation of analogous processes going on independently of life. Between these two courses there seems to me to be no third alternative, unless we suppose that there are two material universes, one to which the material of our bodies belongs, the other comprising everything that is not either plant or animal.

The second reason is a practical one. We should have to go back to the time which I have ventured to call prescientific, when the world of

[1] The words translated in the above sentence are as follows: "Wenn uns endlich die Palme gereicht wird, wenn wir ein Organ in seinem Zuzammenhang begreifen, so wird unser stolzes Gattungsbewusstsein durch die Erkenntniss niedergedruckt, dass der menschlicher Erfinder ein Stümper gegen den unbekannten Meister der thierischen Schöpfung sei."

life and organization was supposed to be governed exclusively by its own laws. The work of the past fifty years has been done on the opposite principle, and has brought light and clearness where there was before obscurity and confusion. All this progress we should have to repudiate. But this would not be all. We should have to forego the prospect of future advance. Whereas by holding on our present course, gradually proceeding from the more simple to the more complex, from the physical to the vital, we may confidently look forward to extending our knowledge considerably beyond its present limits.

A no less brilliant writer than the one already referred to, who is also no longer with us, asserted that mind was a secretion of the brain in the same sense that bile is a secretion of the liver or urine that of the kidney; and many people have imagined this to be the necessary outcome of a too mechanical way of looking at vital phenomena, and that physiologists, by a habit of adhering strictly to their own method, have failed to see that the organism presents problems to which this method is not applicable, such, e. g., as the origin of the organism itself or the origin and development in it of the mental faculty. The answer to this suggestion is that these questions are approached by physiologists only in so far as they are approachable. We are well aware that our business is with the unknown knowable, not with the transcendental. During the last twenty years there has been a considerable forward movement in physiology in the psychological direction, partly dependent on discoveries as to the localization of the higher functions of the nervous system, partly on the application of methods of measurement to the concomitant phenomena of psychical processes; and these researches have brought us to the very edge of a region which can not be explored by our methods, where measurements of time or of space are no longer possible.

In approaching this limit the physiologist is liable to fall into two mistakes; on the one hand, that of passing into the transcendental without knowing it; on the other, that of assuming that what he does not know is not knowledge. The first of these risks seems to me of little moment; first, because the limits of natural knowledge in the psychological direction have been well defined by the best writers, as, e. g., by Du Bois-Reymond in his well-known essay "On the limits of natural knowledge," but chiefly because the investigator who knows what he is about is arrested in limine by the impossibility of applying the experimental method to questions beyond its scope. The other mistake is chiefly fallen into by careless thinkers, who, while they object to the employment of intuition even in regions where intuition is the only method by which anything can be learned, attempt to describe and define mental processes in mechanical terms, assigning to these terms meanings which science does not recognize, and thus slide into a kind of speculation which is as futile as it is unphilosophical.

II. LUDWIG AS INVESTIGATOR AND TEACHER.

The uneventful history of Ludwig's life—how early he began his investigation of the anatomy and function of the kidneys; how he became just fifty years ago titular professor at Marburg, in the small university of his native State, Hesse Cassel; how in 1849 he removed to Zürich as actual professor and thereupon married; how he was six years later promoted to Vienna—has already been admirably related in these pages by Dr. Stirling. In 1865, after twenty years of professorial experience, but still in the prime of life and, as it turned out, with thirty years of activity still before him, he accepted the chair of physiology at Leipzig. His invitation to that great university was by far the most important occurrence in his life, for the liberality of the Saxon Government, and particularly the energetic support which he received from the enlightened Minister Von Falkenstein, enabled him to accomplish for physiology what had never before been attempted on an adequate scale. No sooner had he been appointed than he set himself to create—what was essential to the progress of the science—a great observatory, arranged not as a museum, but much more like a physical and chemical laboratory, provided with all that was needed for the application of exact methods of research to the investigation of the processes of life. The idea which he had ever in view, and which he carried into effect during the last thirty years of his life with signal success, was to unite his life work as an investigator with the highest kind of teaching. Even at Marburg and at Zürich he had began to form a school; for already men nearly of his own age had rallied round him. Attracted in the first instance by his early discoveries, they were held by the force of his character, and became permanently associated with him in his work as his loyal friends and followers—in the highest sense his scholars. If, therefore, we speak of Ludwig as one of the greatest teachers of science the world has seen, we have in mind his relation to the men who ranged themselves under his leadership in the building up of the science of physiology, without reference to his function as an ordinary academical teacher.

Of this relation we can best judge by the careful perusal of the numerous biographical memoirs which have appeared since his death, more particularly those of Professor His[1] (Leipzig), of Professor Kronecker[2] (Bern), who was for many years his coadjutor in the institute, of Professor Von Fick[3] (Würzburg), of Professor Von Kries[4] (Freiburg), of Professor Mosso[5] (Turin), of Professor Fano[6] (Florence), of Professor

[1] His. Karl Ludwig und Karl Thiersch. Akademische Gedächtnissrede, Leipzig, 1895.

[2] Kronecker. Carl Friederich Wilhelm Ludwig. Berliner klin. Wochensch., 1895, No. 21.

[3] A. Fick. Karl Ludwig. Nachruf. Biographische Blätter, Berlin, Vol. I, pt. 3.

[4] Von Kries. Carl Ludwig. Freiburg, Bd. I., 1895.

[5] Mosso. Karl Ludwig. Die Nation, Berlin, Nos. 38, 39.

[6] Fano. Per Carlo Ludwig Commemorazione. Clinica Moderna, Florence, I, No. 7.

Tigerstedt[1] (Upsala), of Professor Stirling[2] in England. With the exception of Fick, whose relations with Ludwig were of an earlier date, and of his colleague in the chair of anatomy, all of these distinguished teachers were at one time workers in the Leipzig Institute. All testify their love and veneration for the master, and each contributes some striking touches to the picture of his character.

All Ludwig's investigations were carried out with his scholars. He possessed a wonderful faculty of setting each man to work at a problem suited to his talent and previous training, and this he carried into effect by associating him with himself in some research which he had either in progress or in view. During the early years of the Leipzig period all the work done under his direction was published in the well-known volumes of the Arbeiten, and subsequently in the Archiv für Anatomie und Physiologie of Du Bois-Reymond. Each "Arbeit" of the laboratory appeared in print under the name of the scholar who operated with his master in its production, but the scholar's part in the work done varied according to its nature and his ability. Sometimes, as Von Kries says, he sat on the window sill, while Ludwig, with the efficient help of his laboratory assistant, Salvenmoser, did the whole of the work. In all cases Ludwig not only formulated the problem, but indicated the course to be followed in each step of the investigation, calling the worker of course into counsel. In the final working up of the results he always took a principal part, and often wrote the whole paper. But whether he did little or much, he handed over the whole credit of the performance to his coadjutor. This method of publication has no doubt the disadvantage that it leaves it uncertain what part each had taken; but it is to be remembered that this drawback is unavoidable whenever master and scholar work together, and is outweighed by the many advantages which arise from this mode of cooperation. The instances in which any uncertainty can exist in relation to the real authorship of the Leipzig work are exceptional. The well-informed reader does not need to be told that Mosso or Schmidt, Brunton or Gaskell, Stirling or Wooldridge were the authors of their papers in a sense very different from that in which the term could be applied to some others of Ludwig's pupils. On the whole, the plan must be judged of by the results. It was by working with his scholars that Ludwig trained them to work afterwards by themselves, and thereby accomplish so much more than other great teachers have done.

I do not think that any of Ludwig's contemporaries could be compared to him in respect of the wide range of his researches. In a science distinguished from others by the variety of its aims, he was equally at home in all branches, and was equally master of all methods, for he recognized that the most profound biological question can only be solved by combining anatomical, physical, and chemical inquiries. It was this consideration which led him in planning the Leipzig Insti-

[1] Tigerstedt. Karl Ludwig. Denkrede. Biographische Blätter, Berlin, Vol. I, pt. 3.
[2] Stirling. Science Progress, Vol. IV, No. 21.

tute to divide it into three parts, experimental (in the more restricted sense), chemical, and histological. Well aware that it was impossible for a man who is otherwise occupied to maintain his familiarity with the technical details of histology and physiological chemistry, he placed these departments under the charge of younger men capable of keeping them up to the rapidly advancing standard of the time, his relations with his coadjutors being such that he had no difficulty in retaining his hold of the threads of the investigation to which these special lines of inquiry were contributory.

It is scarcely necessary to say that as an experimenter Ludwig was unapproachable. The skill with which he carried out difficult and complicated operations, the care with which he worked, his quickness of eye and certainty of hand were qualities which he had in common with great surgeons. In employing animals for experiment he strongly objected to rough and ready methods, comparing them to "firing a pistol into a clock to see how it works." Every experiment ought, he said, to be carefully planned and meditated on beforehand, so as to accomplish its scientific purpose and avoid the infliction of pain. To insure this he performed all operations himself, only rarely committing the work to a skilled coadjutor.

His skill in anatomical work was equally remarkable. It had been acquired in early days, and appeared throughout his life to have given him very great pleasure, for Mosso tells how, when occupying the room adjoining that in which Ludwig was working, as he usually did, by himself, he heard the outbursts of glee which accompanied each successful step in some difficult anatomical investigation.

Let us now examine more fully the part which Ludwig played in the revolution of ideas as to the nature of vital processes which, as we have seen, took place in the middle of the present century.

Although, as we shall see afterwards, there were many men who before Ludwig's time investigated the phenomena of life from the physical side, it was he and the contemporaries who were associated with him who first clearly recognized the importance of the principle that vital phenomena can only be understood by comparison with their physical counterparts, and foresaw that in this principle the future of physiology was contained as in a nutshell. Feeling strongly the fruitlessness and unscientific character of the doctrines which were then current, they were eager to discover chemical and physical relations in the processes of life. In Ludwig's intellectual character this eagerness expressed his dominant motive. Notwithstanding that his own researches had in many instances proved that there are important functions and processes in the animal organism which have no physical or chemical analogues, he never swerved either from the principle or from the method founded upon it.

Although Ludwig was strongly influenced by the rapid progress which was being made in scientific discovery at the time that he

entered on his career, he derived little from his immediate predecessors in his own science. He is sometimes placed among the pupils of the great comparative anatomist and physiologist, J. Müller. This, however, is a manifest mistake, for Ludwig did not visit Berlin until 1847, when Müller was nearly at the end of his career. At that time he had already published researches of the highest value (those on the mechanism of the circulation and on the physiology of the kidney), and had set forth the line in which he intended to direct his investigations. The only earlier physiologist with whose work that of Ludwig can be said to be in real continuity was E. H. Weber, whom he succeeded at Leipzig, and strikingly resembled in his way of working. For Weber Ludwig expressed his veneration more unreservedly than for any other man excepting, perhaps, Helmholtz, regarding his researches as the foundation on which he himself desired to build. Of his colleagues at Marburg he was indebted in the first place to the anatomist, Prof. Ludwig Fick, in whose department he began his career as prosector, and to whom he owed facilities without which he could not have carried out his earlier researches; and in an even higher degree to the great chemist, R. W. Bunsen, from whom he derived that training in the exact sciences which was to be of such inestimable value to him afterwards.

There is reason, however, to believe that, as so often happens, Ludwig's scientific progress was much more influenced by his contemporaries than by his seniors. In 1847, as we learn on the one hand from Du Bois-Reymond, on the other from Ludwig himself, he visited Berlin for the first time. This visit was an important one both for himself and for the future of science, for he there met three men of his own age, Helmholtz, Du Bois-Reymond and Brücke, who were destined to become his life friends, all of whom lived nearly as long as Ludwig himself, and attained to the highest distinction. They all were full of the same enthusiasm. As Ludwig said when speaking of this visit: "We four imagined that we should constitute physiology on a chemico-physical foundation, and give it equal scientific rank with physics, but the task turned out to be much more difficult than we anticipated." These three young men, who were devoted disciples of the great anatomist, had the advantage over their master in the better insight which their training had given them into the fundamental principles of scientific research. They had already gathered around themselves a so-called "physical" school of physiology, and welcomed Ludwig on his arrival from Marburg, as one who had of his own initiative undertaken in his own university das Befreiungswerk aus dem Vitalismus.

The determination to refer all vital phenomena to their physical or chemical counterparts or analogues, which, as I have said, was the dominant motive in Ludwig's character, was combined with another quality of mind, which, if not equally influential, was even more obviously displayed in his mode of thinking and working. His first aim,

even before he sought for any explanation of a structure or of a process, was to possess himself, by all means of observation at his disposal, of a complete objective conception of all its relations. He regarded the faculty of vivid, sensual realization (lebendige sinnliche Anschauung) as of special value to the investigator of natural phenomena, and did his best to cultivate it in those who worked with him in the laboratory. In himself this objective tendency (if I may be permitted the use of a word which, if not correct, seems to express what I mean) might be regarded as almost a defect, for it made him indisposed to appreciate any sort of knowledge which deals with the abstract. He had a disinclination to philosophical speculation which almost amounted to aversion, and, perhaps for a similar reason, avoided the use of mathematical methods even in the discussion of scientific questions which admitted of being treated mathematically—contrasting in this respect with his friend, Du Bois-Reymond—resembling Brücke. But as a teacher the quality was of immense use to him. His power of vivid realization was the substratum of that many-sidedness which made him, irrespectively of his scientific attainments, so attractive a personality.

I am not sure that it can be generally stated that a keen scientific observer is able to appreciate the artistic aspects of nature. In Ludwig's case, however, there is reason to think that æsthetic faculty was as developed as the power of scientific insight. He was a skillful draftsman but not a musician; both arts were, however, a source of enjoyment to him. He was a regular frequenter of the Gewandhaus concerts, and it was his greatest pleasure to bring together gifted musicians in his house, where he played the part of an intelligent and appreciative listener. Of painting he knew more than of music, and was a connoisseur whose opinion carried weight. It is related that he was so worried by what he considered bad art, that after the redecoration of the Gewandhaus concert room he was for some time deprived of his accustomed pleasure in listening to music.

Ludwig's social characteristics can only be touched on here in so far as they serve to make intelligible his wonderful influence as a teacher. Many of his pupils at Leipzig have referred to the schöne gemeinsamkeit which characterized the life there. The harmonious relation which, as a rule, subsisted between men of different education and different nationalities could not have been maintained had not Ludwig possessed side by side with that inflexible earnestness which he showed in all matters of work or duty a certain youthfulness of disposition which made it possible for men much younger than himself to accept his friendship. This sympathetic geniality was, however, not the only or even the chief reason why Ludwig's pupils were the better for having known him. There were not a few of them who for the first time in their lives came into personal relation with a man who was utterly free from selfish aims and vain ambitions, who was scrupulously conscientious in all that he said and did, who was what he seemed and

seemed what he was, and who had no other aim than the advancement of his science, and in that advancement saw no other end than the increase of human happiness. These qualities displayed themselves in Ludwig's daily active life in the laboratory, where he was to be found whenever work of special interest was going on; but still more when, as happened on Sunday mornings, he was "at home" in the library of the institute—the corner room in which he ordinarily worked. Many of his "scholars" have put on record their recollections of these occasions, the cordiality of the master's welcome, the wide range and varied interest of his conversation, and the ready appreciation with which he seized on anything that was new or original in the suggestions of those present. Few men live as he did, "im Gaznen, Guten, Schönen," and of those still fewer know how to communicate out of their fullness to others.

III. THE OLD AND THE NEW VITALISM.

Since the middle of the century the progress of physiology has been continuous. Each year has had its record, and has brought with it new accessions to knowledge. In one respect the rate of progress was more rapid at first than it is now, for in an unexplored country discovery is relatively easy. In another sense it was slower, for there are now scores of investigators for every one that could be counted in 1840 or 1850. Until recently there has been throughout this period no tendency to revert to the old methods—no new departure—no divergence from the principles which Ludwig did so much to enforce and exemplify.

The wonderful revolution which the appearance of the Origin of Species produced in the other branch of biology promoted the progress of physiology, by the new interest which it gave to the study, not only of structure and development, but of all other vital phenomena. It did not, however, in any sensible degree affect our method or alter the direction in which physiologists had been working for two decades. Its most obvious effect was to sever the two subjects from each other. To the Darwinian epoch comparative anatomy and physiology were united, but as the new ontology grew it became evident that each had its own problems and its own methods of dealing with them.

The old vitalism of the first half of the century is easily explained. It was generally believed that, on the whole, things went on in the living body as they do outside of it, but when a difficulty arose in so explaining them the physiologist was ready at once to call in the aid of a "vital force." It must not, however, be forgotten that, as I have already indicated, there were great teachers (such, for example, as Sharpey and Allen Thomson in England, Magendie in France, Weber in Germany) who discarded all vitalistic theories, and concerned themselves only with the study of the time and place relations of phenomena; men who were before their time in insight, and were only hindered in their application of chemical and physical principles to

the interpretation of the processes of life by the circumstance that chemical and physical knowledge was in itself too little advanced. Comparison was impossible, for the standards were not forthcoming.

Vitalism in its original form gave way to the rapid advance of knowledge as to the correlation of the physical sciences which took place in the forties. Of the many writers and thinkers who contributed to that result, J. R. Mayer and Helmholtz did so most directly, for the contribution of the former to the establishment of the doctrine of the conservation of energy had physiological considerations for its point of departure; and Helmholtz, at the time he wrote the Erhaltung der Kraft, was still a physiologist. Consequently when Ludwig's celebrated Lehrbuch came out in 1852, the book which gave the coup de grâce to vitalism in the old sense of the word, his method of setting forth the relations of vital phenomena by comparison with their physical or chemical counterparts, and his assertion that it was the task of physiology to make out their necessary dependence on elementary conditions, although in violent contrast with current doctrine, were in no way surprising to those who were acquainted with the then recent progress of research. Ludwig's teaching was indeed no more than a general application of principles which had already been applied in particular instances.

The proof of the nonexistence of a special "vital force" lies in the demonstration of the adequacy of the known sources of energy in the organism to account for the actual day by day expenditure of heat and work; in other words, on the possibility of setting forth an energy balance sheet in which the quantity of food which enters the body in a given period (hour or day) is balanced by an exactly corresponding amount of heat produced or external work done. It is interesting to remember that the work necessary for preparing such a balance sheet (which Mayer had attempted, but from want of sufficient data failed in) was begun thirty years ago in the laboratory of the Royal Institution by the foreign secretary of the royal society. But the determinations made by Dr. Frankland related to one side of the balance sheet, that of income. By his researches in 1866 he gave physiologists for the first time reliable information as to the heat value (i. e., the amount of heat yielded by the combustion) of different constituents of food. It still remained to apply methods of exact measurement to the expenditure side of the account. Helmholtz had estimated this, as regards man, as best he might, but the technical difficulties of measuring the expenditure of heat of the animal body appeared until lately to be almost insuperable. Now that it has been at last successfully accomplished, we have the experimental proof that in the process of life there is no production or disappearance of energy. It may be said that it was unnecessary to prove what no scientifically sane man doubted. There are, however, reasons why it is of importance to have objective evidence that food is the sole and adequate source of the energy which

we day by day or hour by hour disengage, whether in the form of heat or external work.

In the opening paragraph of this section it was observed that *until recently* there had been no tendency to revive the vitalistic notion of two generations ago. In introducing the words in italics I referred to the existence at the present time in Germany of a sort of reaction, which under the term "Neovitalismus" has attracted some attention—so much indeed that at the Versammlung Deutscher Naturforscher at Lübeck last September it was the subject of one of the general addresses. The author of this address, Professor Rindfleisch, was, I believe, the inventor of the word; but the origin of the movement is usually traced to a work on physiological chemistry which an excellent translation by the late Dr. Wooldridge has made familiar to English students. The author of this work owes it to the language he employs in the introduction on "Mechanism and vitalism" if his position has been misunderstood, for in that introduction he distinctly ranges himself on the vitalistic side. As, however, his vitalism is of such a kind as not to influence his method of dealing with actual problems, it is only in so far of consequence as it may affect the reader. For my own part I feel grateful to Professor Bange for having produced an interesting and readable book on a dry subject, even though that interest may be partly due to the introduction into the discussion of a question which, as he presents it, is more speculative than scientific.

As regards other physiological writers to whom vitalistic tendencies have been attributed, it is to be observed that none of them has even suggested that the doctrine of a "vital force" in its old sense should be revived. Their contention amounts to little more than this, that in certain recent instances improved methods of research appear to have shown that processes at first regarded as entirely physical or chemical do not conform so precisely as they were expected to do to chemical and physical laws. As these instances are all essentially analogous, reference to one will serve to explain the bearing of the rest.

Those who have any acquaintance with the structure of the animal body will know that there exists in the higher animals, in addition to the system of veins by which the blood is brought back from all parts to the heart, another less considerable system of branched tubes, the lymphatics, by which, if one may so express it, the leakage of the blood vessels is collected. Now, without inquiring into the why of this system, Ludwig and his pupils made and continued for many years elaborate investigations which were for long the chief sources of our knowledge, their general result being that the efficient cause of the movement of the lymph, like that of the blood, was mechanical. At the Berlin Congress in 1890 new observations by Professor Heidenhain, of Breslau, made it appear that under certain conditions the process of lymph formation does not go on in strict accordance with the physical laws by which leakage through membranes is regulated, the experi-

mental results being of so unequivocal a kind that, even had they not been confirmed, they must have been received without hesitation. How is such a case as this to be met? The "Neovitalists" answer promptly by reminding us that there are cells, i. e., living individuals, placed at the inlets of the system of drainage without which it would not work, that these let in less or more liquid according to circumstances, and that in doing so they act in obedience, not to physical laws, but to vital ones—to internal laws which are special to themselves.

Now, it is perfectly true that living cells, like working bees, are both the architects of the hive and the sources of its activity, but if we ask how honey is made it is no answer to say that the bees make it. We do not require to be told that cells have to do with the making of lymph as with every process in the animal organism, but what we want to know is how they work, and to this we shall never get an answer so long as we content ourselves with merely explaining one unknown thing by another. The action of cells must be explained, if at all, by the same method of comparison with physical or chemical analogues that we employ in the investigation of organs.

Since 1890 the problem of lymph formation has been attacked by a number of able workers, among others here in London, by Dr. Starling, of Guy's Hospital, who, by sedulously studying the conditions under which the discrepancies between the actual and the expected have arisen, has succeeded in untying several knots. In reference to the whole subject, it is to be noticed that the process by which difficulties are brought into view is the same as that by which they are eliminated. It is one and the same method throughout, by which, step by step, knowledge perfects itself—at one time by discovering errors, at another by correcting them; and if at certain stages in this progress difficulties seem insuperable we can gain nothing by calling in even provisionally the aid of any sort of eidolon, whether "cell," "protoplasm," or internal principle.

It thus appears to be doubtful whether any of the biological writers who have recently professed vitalistic tendencies are in reality vitalists. The only exception that I know is to be found in the writings of a well-known morphologist, Dr. Hans Driesch,[1] who has been led by his researches on what is now called the mechanics of evolution to revert to the fundamental conception of vitalism that the laws which govern vital processes are not physical, but biological—that is, peculiar to the living organism and limited thereto in their operation. Dr. Driesch's researches as to the modifications which can be produced by mechanical interference in the early stages of the process of ontogenesis have enforced upon him considerations which he evidently regards as new, though they are familiar enough to physiologists. He recognizes that

[1] Driesch. Entwicklungsmechanische Studien. A series of ten papers, of which the first six appeared in the Zeitsch. f. w. Zoologie, Vols. LIII and LV; the rest in the Mittheilungen of the Naples Station.

although by the observation of the successive stages in the ontogenetic process one may arrive at a perfect knowledge of the relation of these stages to each other, this leaves the efficient causes of the development unexplained (führt nicht zu einem Erkenntniss ihrer bewirkenden Ursachen). It does not teach us why one form springs out of another. This brings him at once face to face with a momentous question. He has to encounter three possibilities. He may either join the camp of the biological agnostics and say with Du Bois-Reymond "ignoramus et ignorabimus," or be content to work on in the hope that the physical laws that underlie and explain organic evolution may sooner or later be discovered, or he may seek for some hitherto hidden law of organism of which the known facts of ontogenesis are the expression, and which, if accepted as a law of nature, would explain everything. Of the three alternatives Driesch prefers the last, which is equivalent to declaring himself an out-and-out vitalist. He trusts by means of his experimental investigations of the mechanics of evolution to arrive at "elementary conceptions" on which by "mathematical deduction"[1] a complete theory of evolution may be founded.

If this anticipation could be realized, if we could construct with the aid of those new principia the ontogeny of a single living being, the question whether such a result was or was not inconsistent with the uniformity of nature would sink into insignificance as compared with the splendor of such a discovery.

But will such a discovery ever be made? It seems to me even more improbable than that of a physical theory of organic evolution. It is satisfactory to reflect that the opinion we may be led to entertain on this theoretical question need not affect our estimate of the value of Dr. Driesch's fruitful experimental researches.

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[1] "Elementarvorstellungen . . . die zwar mathematische Deduktion aller Erscheinungen aus sich gestatten möchten." Driesch. Beiträge zur theoretischen Morphologie. Biol. Centralblatt, Vol. XII, p. 539, 1892.

THE PROCESSES OF LIFE REVEALED BY THE MICROSCOPE; A PLEA FOR PHYSIOLOGICAL HISTOLOGY.[1]

By SIMON HENRY GAGE, B. S.,
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It is characteristic of the races of men that almost at the dawn of reflection the first question that presses for solution is this one of life—life as manifested in men and in the animals and plants around them. What and whence is it, and whither does it tend? Then the sky with its stars, the earth with its sunshine and storm, light and darkness, stand out like great mountain peaks demanding explanation. So in the life of every human being, repeating the history of his race, as the evolutionists are so fond of saying, the fundamental questions are first to obtrude themselves upon the growing intelligence. There is no waiting, no delay for trifling with the simpler problems; the most fundamental and most comprehensive come immediately to the fore and alone seem worthy of consideration. But as age advances most men learn to ignore the fundamental questions and to satisfy themselves with simpler and more secondary matters, as if the great realities were all understood or nonexistent. No doubt to many a parent engaged in the affairs of society, politics, finance, science, or art, the questions that their children put, like drawing aside a thick curtain, bring into view the fundamental questions, the great realities; and we know again that what is absorbing the power and attention of our mature intellect, what perhaps in pride we feel a mastery over, are only secondary matters after all, and to the great questions of our own youth, repeated with such earnestness by our children, we must confess with humility that we still have no certain answers. It behooves us, then, if the main questions of philosophy and science can not be answered at once, to attempt a more modest task, and by studying the individual factors of the problem to hope ultimately to put these together and thus gain some just comprehension of the entire problem.

This address is, therefore, to deal, not with life itself, but with some of the processes or phenomena which accompany its manifestations. But it is practically impossible to do fruitful work according to the Baconian guide of piling observation on observation. This is very

[1] Address of the president of the American Microscopical Society. Printed in Transactions of the American Microscopical Society, Vol. XVII, 1896, pages 3–29.

liable to be a dead mass, devoid of the breath of life. It is a well-known fact that the author of the Novum Organuon, the key which Bacon supposed would serve as the open sesame of all difficulties and yield certain knowedge, this potent key did not unlock many of the mysteries of science for its inventor. Every truly scientific man since the world began has recognized the necessity of accurate observation, and no scientific principle has ever yet been discovered simply by speculation; but every one who has really unlocked any of the mysteries of nature has inspired, made alive his observations by the imagination; he has, as Tyndall so well put it, made a scientific use of the imagination and created for himself what is known as the "working hypothesis." It must be confessed that for some investigators the "hypothesis" becomes so dear that if the facts of nature do not conform to the hypothesis, "so much the worse for the facts." But for the truly scientific man the hypothesis is destined solely to enable him to get the facts of nature in some definite order, an order which shall make apparent their connection with the great order and harmony which is believed to be present in the universe.

If the working hypothesis fails in any essential particular, he is ready to modify or discard it. For the truly inspired investigator one undoubted fact weighs more in the balance than a thousand theories.

At the very threshold of any working hypothesis for the biologist, this question as to the nature of the energy we call life must be considered. The great problem must receive some kind of a hypothetical solution. What is its relation to the energies of light, heat, electricity, chemism, and the other forms discussed by the physicist? Are its complex manifestations due only to these, or does it have a character and individuality of its own? If we accept the ordinarily received view of the evolution of our solar system, the original fiery nebula, in which heat reigned supreme, slowly dissipated part of its heat, and hurled into space the planets, themselves flaming vapors, only the protons of the solid planets. As the heat became further dissipated there appeared in the cooling mass manifestations of chemical attraction, compounds, at first gases, then liquids, and finally, on the cooling planets, solids appeared. Lastly upon our own planet, the earth, when the solid crust was formed and the temperature had fallen below the boiling point of water, the seas were formed and then life appeared. Who could see, in the incandescent nebula, the liquids and solids of our planet and the play upon them of chemism, of light, heat, electricity, cohesion, tension, and the other manifestations so familiar to all? And yet, who is there that for a moment believes that aught of matter or energy was created in the different stages of the evolution? They appeared or were manifested just as soon as the conditions made it possible. So it seems to me that the energy called life manifested itself upon this planet when the conditions made it possible, and it will cease to manifest itself just as soon as the conditions become sufficiently

unfavorable. It was the last of the forms of energy to appear upon this planet and it will be the first to disappear.

In brief, it seems to me that the present state of physical and physiological knowledge warrants the assumption, the working hypothesis, that life is a form of energy different from those considered in the domain of physics and chemistry. This form of energy is the last to appear, last because more conditions were necessary for its manifestations. It, like the other forms of energy, requires a material vehicle through which to act, but the results produced by it are vastly more complex. Like the other energies of nature, it does not act alone. It acts with the energies of the physicist, but as the master; and under its influence the manifestations pass infinitely beyond the point where for the ordinary energies of nature it is written "thus far and no farther."

It can be stated without fear of refutation that every physiological investigation shows with accumulating emphasis that the manifestations of living matter are not explicable with only the forces of dead matter, and the more profound the knowledge of the investigator the more certain is the testimony that the life energy is not a mere name. And, strange to say, the physicist and the chemist are most emphatic in declaring that life is an energy outside their domain.

The statements of a chemist, a physicist, and a biologist are added. From the character and attainments of these men, their testimony, given after years of the most earnest investigation and reflection, is worthy of consideration:

When a celebrated chemist was asked if he believed that a leaf or a flower could be formed or could grow by chemical forces, he answered:

> I would more readily believe that a book on chemistry or on botany could grow out of dead matter by chemical processes.—Liebig.

> The influence of animal or vegetable life on matter is infinitely beyond the range of any scientific inquiry hitherto entered on. Its power of directing the motions of moving particles, in the demonstrated daily miracle of our human free will, and in the growth of generation after generation of plants from a single seed, are infinitely different from any possible result of the fortuitous concourse of atoms; and the fortuitous concourse of atoms is the sole foundation in philosophy on which can be founded the doctrine that it is impossible to derive mechanical effect from heat otherwise than by taking heat from a body at a higher temperature, converting at most a definite proportion of it into mechanical effect, and giving out the whole residue to matter at a lower temperature.—Sir William Thomson (Lord Kelvin).

> The anagenetic [vital] energy transforms the face of nature by its power of assimilating and recompounding inorganic matter, and by its capacity for multiplying its individuals. In spite of the mechanical destructibility of its physical basis (protoplasm) and the ease with which its mechanisms are destroyed, it successfully resists, controls, and remodels the catagenetic [physical and chemical] energies for its purpose.—Cope.

What, then, are the manifestations of the life energy? and what are the processes which are discernible? All of us, in whatever walk of life, will recognize the saying of Gould:

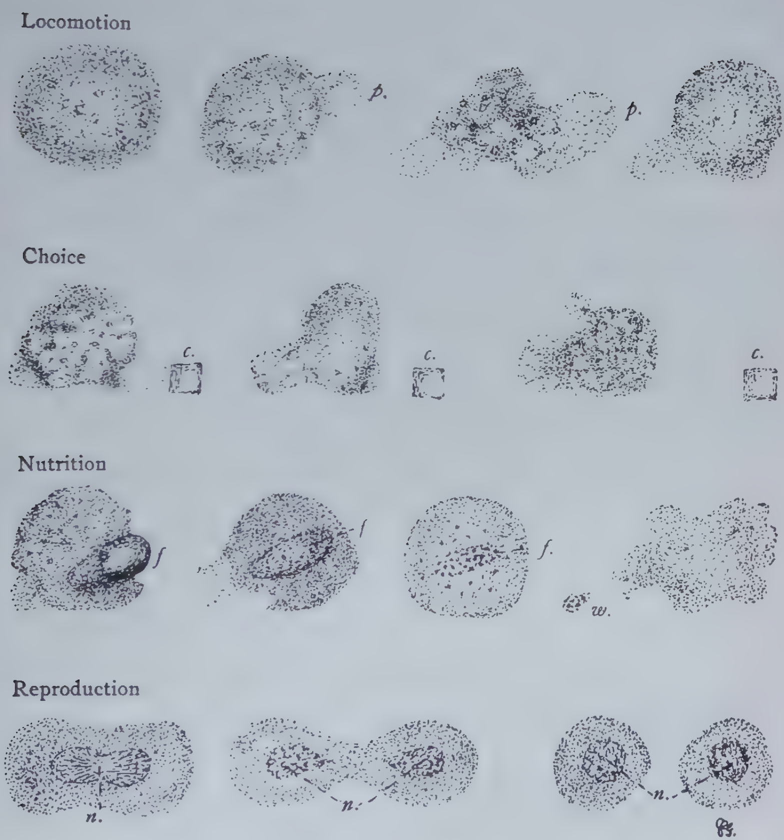
> Now, when one looks about him the plainest, largest fact he sees is that of the distinction between living and lifeless things.

As life goes on and works with power where the unaided eye fails to detect it, the microscope—marvelous product of the life energy in the brain of man—shows some of these hidden processes. It has done for the infinitely little on the earth what the telescope has done for the infinitely great in the sky.

Let us commence with the little and the simple. If a drop of water from an aquarium, stream, or pool is put under the microscope many things appear. It is a little world that one looks into, and like the greater one that meets our eye on the streets, some things seem alive and some lifeless. As we look we shall probably find, as in the great world, that the most showy is liable in the end to be the least interesting. In the microscopic world there will probably appear one or more small rounded masses which are almost colorless. If one of these is watched, lo! it moves, not by walking or swimming, but by streaming itself in the direction. First a slender or blunt knob appears, then into it all of the rest of the mass moves, and thus it has changed its position. If the observation is continued, this living speck, which is called an amœba, will be seen to approach some object and retreat, indeed, it comports itself as if sensitive, with likes and dislikes. If any object suitable for food is met in its wanderings the living substance flows around it, engulfs it and dissolves the nutrient portions and turns them into its own living substance; the lifeless has been rendered alive. If the eye follows the speck of living matter the marvels do not cease. After it has grown to a certain size, as if by an invisible string, it constricts itself in the middle and finally cuts itself in two. The original amœba is no more, in its place there are two. Thus nearly at the bottom of the scale of life are manifested all of the fundamental features—the living substance moves itself, takes nourishment, digests it and changes nonliving into living substance and increases in size; it seems to feel and to avoid the disagreeable and choose the agreeable, and finally it performs the miracle of reproducing its kind, of giving out its life and substance to form other beings, its offspring.

It is the belief of many biologists that the larger and complex forms, even up to man himself, may be considered an aggregation of structural elements originally more or less like the amœba just described; but instead of each member of the colony, each individual itself carrying on all the processes of life independently, as with the amœba, there is a division of labor. Some move, some digest, some feel, think, and choose, some give rise to new beings, all change lifeless matter into their own living substance. (See Plate XI.)

The processes and phenomena by which a new individual is produced are included under the comprehensive term embryology.



PROCESSES OF LIFE REVEALED BY THE MICROSCOPE.

FIG. 1. The amœba in its various phases of activity—locomotion, choice (irritability), nutrition, and reproduction. The figures should be read from left to right, as with words in a book. *p*, Pseudopod; *c*, crystal of substance distasteful to the amœba, hence the amœba withdraws from it; *f*, food ingested and digested by the amœba for its nourishment. The indigestible matter (*w*) is extruded from the body and left behind. *n*, Nucleus. This is seen to divide first in reproduction, then the division of the cell body is completed, thus giving rise to two individuals.

All organisms, great or small, are but developments of minute germs budded off by the parent or parents, and the way in which these minute beginnings develop into perfect forms like their parents can only be followed by the aid of a microscope. Indeed, in no field of biology has the microscope done such signal service in revealing the processes of life.

The method of the production of a new being with the amœba, as we have just seen, is for the parent to give itself entire to its offspring—the parent ceasing to be in producing its offspring. With some other lowly forms a part of the body of the parent buds out, grows, and finally falls off as an independent organism or remains connected with the parent to form a colony. In the vegetable world a familiar example of a colony is represented by the plant that the children call "old hen and chickens."

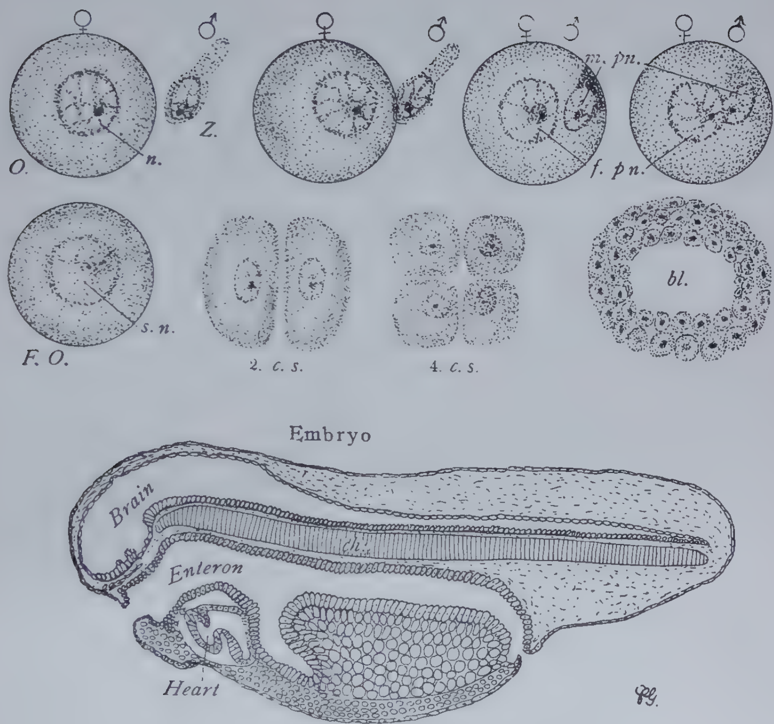
In the higher animals, however, where specialization is carried to its extreme limit, some myriads of cells forming the body are set apart to produce motion, others digest food, still others think and feel, while comparatively few, the germ cells, are destined for the continuation of the race. In the higher and highest forms especially, all observation goes to show that the life energy, not satisfied with the mere vitalization of matter and a dead level of excellence, is aiming at perpetual ascent, greater mastery over matter and its physical forces. For the more certain attainment of this end, the production of offspring is no longer possible for one individual; two wholly separate individuals must join, each contributing its share of the living matter which is to develop into a new being. In this way the accumulated acquirements of two are united with the consequent increase in the tendencies and impulses for modification and nearly double the protection for the offspring. Thus, in striking contrast to the amœba, where the single parent gives all of itself to form offspring and in so doing disappears and loses its identity, in the higher forms, while two must unite to form the offspring, the parents remain and retain their individuality and the ability to produce still other offspring. The process by which this is accomplished may be traced step by step with the microscope. A germ cell of the father and one of the mother fuse together, and from this new procreative cell formed by the fusion of two, with all their possibilities combined, the new individual arises. This certain knowledge is the result of the profound investigation of the last few years, and shows the literalness of the scriptural statement, "they shall be one flesh." (See Plate XII.)

After this fusion of the father and mother germ cells the single cell thus formed, like the amœba, divides into two, and these into four and so on, but unlike the amœba all the cells remain together. Within this cellular mass, as if by an unseen builder, the cells are deftly arranged in their place, some to form brain, some heart, some the digestive tract, others for movement; so that finally from the simple mass of cells, originally so alike, arises the complex organism, fish or bird, beast or

man. How perfectly the word "offspring" describes the life process in the production of this new being! That the child should resemble both father and mother is thus made intelligible, for it is a part of both. Yes, further, it may resemble grandfather or great grandfather or mother, for truly it is a part of them, their life conserved and continued. There is no new life, it is only a continuation of the old. "Omne vivum ex vivo," all life from life. But the demonstration of this prime fact required a microscope, and it is an achievement of the last half of this century. How counter this statement still is to the common belief of mankind we may perhaps better appreciate if we recall our own youth, and remember with what absolute confidence we expected the stray horsehairs we had collected and placed in water to turn into living snakes.[1] The belief that it is an everyday occurrence for living beings to arise from lifeless matter was not by any means confined to those uneducated in biology. It was held by many scientific men within the memory of most of us. Indeed this goblin of spontaneous generation, even for the scientific world, has been laid low so recently that the smoke of battle has scarcely yet cleared from the horizon.

In the complex body of animals, as stated above, the constituent elements perform different functions. Is there any hint of the way in which the action is accomplished? Let us glance at two systems, the nervous and the glandular, widely different in structure and function. All know how constantly the glands are called into requisition, the salivary glands for saliva, those of the stomach and the pancreas for their digestive juices, etc. If we take now the pancreas as an example, and that of a living, fasting animal is put under the microscope so that its constituent cells can be observed, it will be seen that they are clouded, their outlines and that of their nuclei being vague and indistinct. The cell is apparently full of coarse grains. If now the animal is fed, as the digestion proceeds the pancreas pours out its juice. At the same time the granules, and with them the cloudiness, gradually disappear, the cells become clear, and both they and their nuclei are sharply outlined. That is, the substance which is to form the pancreatic juice is stored in the cells in the form of granules during the periods of rest, and held until the digestive agent is demanded, and if the demand is great all the granules may be used up. But as soon as the demand ceases the cells begin again their special vital

[1] Reference is here made to the nematoid worm *Gordius*. This worm lives a part of its life as a parasite in the larvæ of aquatic insects and in some fish. In the adult free condition it differs markedly from the larval, parasitic stage, and is very slender and much elongated, often reaching a length of 20 to 30 centimeters (8 to 10 inches), and has the general appearance of a coarse hair like that from the tail of a horse. It lives in water and in wet places, and frequently appears in horse troughs and the wet places where the trough overflows. From the hair-like appearance it was and still is believed that a hair from the horse's tail or mane had directly transformed into a living creature. By many persons it is called a hair snake, by others a hair worm. Often one or several become tangled in an almost inextricable knot, whence the name from the famous "Gordian knot."



PROCESSES OF LIFE REVEALED BY THE MICROSCOPE.

FIG. 2. Various phases in the reproduction of one of the higher animals. In the upper series is shown the fusion of the father and mother germ cells; in the middle series appear some of the earlier phases of segmentation of the fertilized ovum. The lower figure (modified from Marshall) represents a medisection of an amphibian embryo sufficiently far advanced to show that the original cells into which the ovum divided have differentiated and arranged themselves in such a manner as to form the beginnings or protons of the great systems of organs—brain, enteron, and heart.

O, Ovum; *n*, nucleus of the ovum. ♀ This sign indicates that the ovum is a mother or female germ cell. *Z*, Zoosperm. ♂ Sign indicating that the zoosperm is a father or male germ cell. *f pn*, Female pronucleus; *m pn*, male pronucleus. These two pronuclei fuse and form the nucleus of the true reproductive cell, the fertilized ovum. In the two figures at the right both signs (♀♂) are used to indicate that both germ cells are represented in each figure.

F O, Fertilized ovum. That is the true reproductive cell, composed of a father or male and a mother or female germ cell fused. The steps of the fusion are shown in the upper series. *s n*, Segmentation nucleus. *2 c s*, Two-cell stage; that is, the fertilized ovum has divided once, forming two. (Compare the reproduction of the amœba.) *4 c s*, Four-cell stage. *bl*, Blastula stage, in which the fertilized ovum has divided into very many cells, all remaining together.

Embryo.—The division of the organs has proceeded very far, and the cells have begun to differentiate and form organs: *Brain*; *ch.* body axis, or notochord; *Enteron*, or alimentary canal, and *Heart*.

action, and again the granules begin to appear and increase in number until finally the cells become so full that they are fully charged and again ready to pour forth the digestive fluid. This is a daily, almost an hourly process. (See Plate XIII.)

Let us take another example in which it would almost appear that there is organic memory on the part of the gland cells. No doubt all have seen the clear jelly-like masses surrounding the eggs of frogs and salamanders. Whence comes this jelly that is so resistant to the agents that work so quickly the destruction of ordinary organic matter? As spring advances the cells of the oviduct increase enormously in size. The microscope shows this increase to be due to a multitude of clear granules. As the eggs move along, the ova are coated with the jelly formed from the granules given out by the cells. As this material for the jelly is poured out the cells gradually shrink to their original size, and then wait another twelve months before doing their destined work.

If one can thus catch a glimpse of some of the finer processes taking place in gland action, how is it with nervous action, the highest function of which living matter is capable? While it has been known for a long time that the nervous system is the organ of thought and feeling and the director and coordinator of the motions of the body, and many speculations had been made concerning the processes through which the nervous tissue passes in performing its functions, it was left to an American student, Dr. Hodge, to first successfully show that there were visible changes through which the nervous system passes in its work. The question is, can the activity of the nervous system be traced as surely by changes occurring in the living matter forming its basis, as the action of a gland can be seen by the study of the gland cells?

The demonstration is simple now that the method has been shown. No doubt everyone has had the experience of failing to perform some difficult muscular action at one time and then at another of doing it with ease, or of finding true the reverse of the adage, "practice makes perfect." For example, in a trial of skill, as in learning to ride a bicycle, all the complicated action may be performed with considerable ease and certainty at the beginning of a lesson, when one is fresh, but as the practice continues the results become progressively less and less successful, and finally with increasing weariness there is only failure, and one must rest. We say the muscles are tired. This is true in part, but of much greater importance is the fatigue of the nervous system, as this furnishes the impulses for the action and coordination of the muscles. Now, as muscular action can be seen and the amount can be carefully controlled, here was an exact indicator of the time and amount of the nervous activity. Furthermore, as animals have two similar sides, one arm or leg may work and the other remain at rest, and consequently corresponding sides of the nervous system may be active and at rest. By means of electrical irritation one arm of a cat or other animal was caused to move vigorously for a considerable time,

the other arm remaining at rest. Then the two sides of the nervous system—that is, the pairs of nerves to the arms with their ganglia and a segment of the myel (spinal cord)—were removed and treated with fixing agents, and carried through all the processes necessary to get thin sections capable of accurate study with the microscope. Finally upon the same glass slide are parts of the nervous system fatigued even to exhaustion, and corresponding parts of the same animal which had been at rest. Certainly if the nervous substance shows the result or processes of its action the conditions are here perfect. Fatigued nerve cells are side by side with those in a state of rest. The appearances are clear and unmistakable. The nucleus has markedly decreased in size in the fatigued cells and possesses a jagged, irregular outline in place of the smooth, rounded form of the resting cells. The cell substance is shrunken in size and possesses clear, scattered spaces, or a large, clear space around the nucleus.

If the nervous substance was not fixed at once but remained in the living animal for twelve to twenty-four hours in a state of repose, the signs of exhaustion disappeared and the two sides appeared alike. By studying preparations made after various periods of repose all the stages of recovery from exhaustion could be followed.

For possible changes in normal fatigue, sparrows, pigeons, and swallows, and also honeybees, were used. For example, if two sparrows or two honeybees as nearly alike as possible were selected, the nervous system of one being fixed in the morning after the night's rest and that of the other after a day of toil, the changes in the cells of the brain of the honeybee or sparrow and in the spinal ganglia of the sparrow were as marked as in case of artificial fatigue. After prolonged rest, then, the nerve cells are, so to speak, charged; they are full and ready for labor; but after a hard day's work they are discharged—shrunken and exhausted. (See Plate XIV.)

There is one more step in this brilliant investigation. If in the morning, after sleep and rest, animals and men are full of vigor, and in the evening are weary and exhausted, how like is it to the beginning and end of life? In youth so overflowing with vigor that to move, to act, is pleasure, and continued rest a pain; but in the evening of life a warm corner and repose are what we try to furnish those whose work is done. How is this correlated in the cells of the nervous system with the states of rest and fatigue? With a well-nourished child which died from one of the accidents of birth the nerve cells showed all the characters of cells at rest and fully charged. In a man dying naturally of old age the cells showed the shrunken nuclei and all the appearances of exhausting fatigue. In the one was the potentiality of a life of vigorous action; the other showed the final fatigue—the store of life energy had been dissipated, and there was no recovery possible.

For the animals that possess an undoubted nervous system probably all would admit that there is some sort of nervous action corresponding

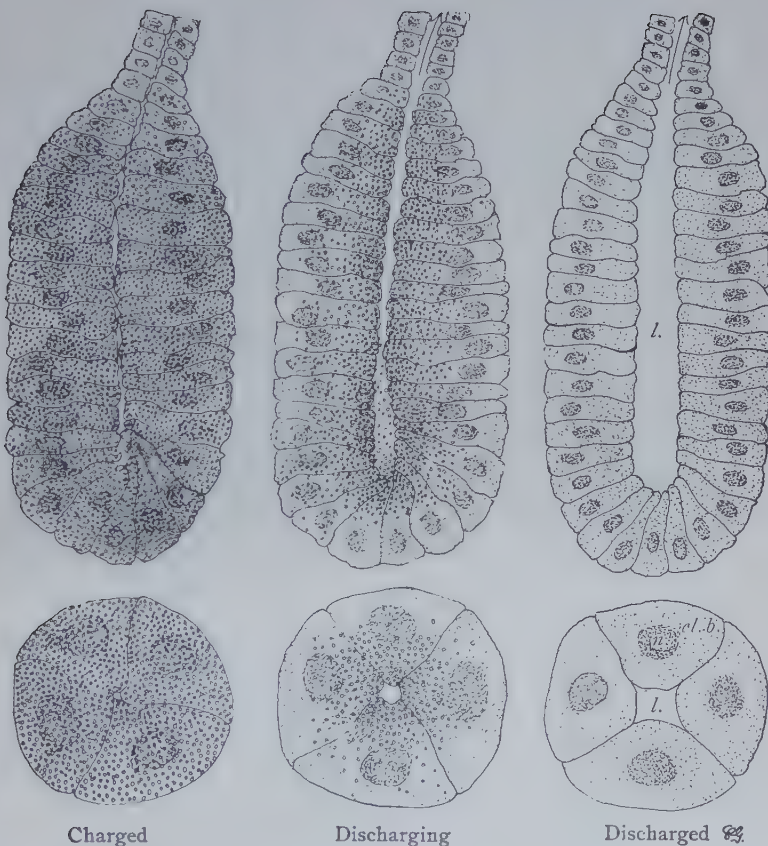


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FIG. 3. Sections of a gland in various phases of activity. The upper series represents the gland as in longisection or lengthwise and the lower series as in transection or cut across. In the longisections *l*, in the right-hand figure, represents the cavity or lumen of the gland into which the secretion of the gland is poured. The arrows at the top represent the direction taken by the secretion when it is poured out.

In the lower right-hand figure *l* represents the lumen, *n* the nucleus of one of the cells, and *cl b* the cell body of the same cell. The words Charged, Discharging, and Discharged designate the various phases of the gland activity. The process of becoming recharged is not shown.

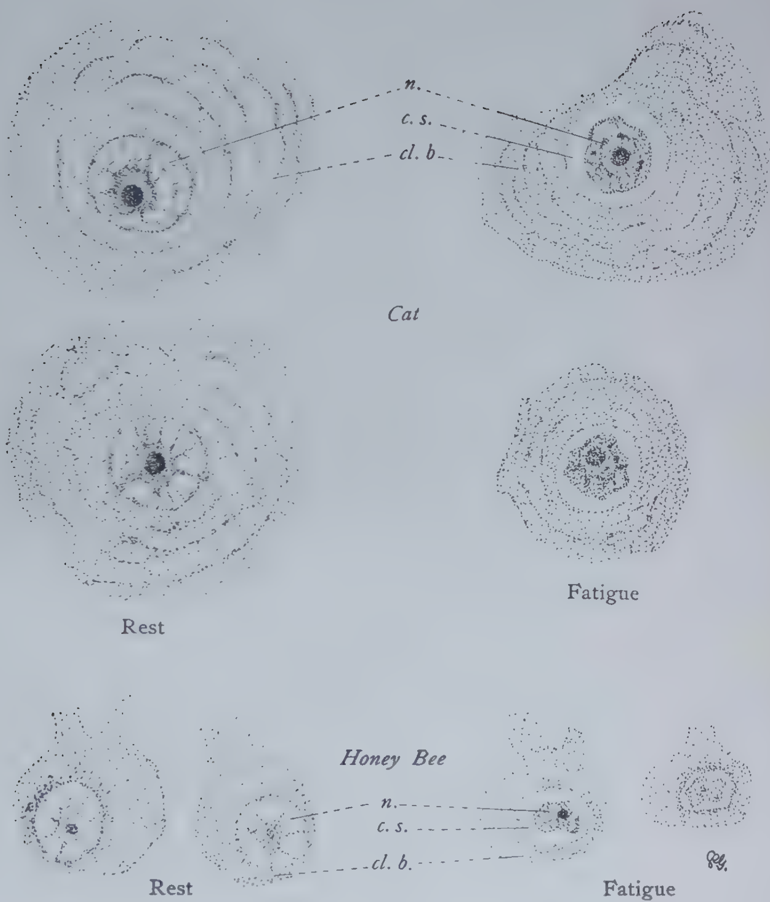

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FIG. 4. Figures from Hodge (Jour. Morphology, Vol. VII), showing changes in the nerve cells of the spinal ganglia in the cat and of the brain in the honey bee. The words Rest and Fatigue indicate the appearance of the cells in these two conditions. *n*, Nucleus; *cl b*, cell body, and *c s* clear space around the shrunken nucleus in the fatigued cells.

to sensation: but what of living matter in the humbler forms where no nervous system can be found? That these have vital motion, that they breathe, nourish themselves, grow, and produce offspring, none can deny. Do they have anything comparable with sensation? As most of the lowest forms are minute, the microscope comes to our aid again, and in watching these lowliest living beings it is found that they discriminate and choose, going freely into some portions of their liquid world and withdrawing from other portions. If some drug which is unusual or we must believe disagreeable is added to a part of the water, they withdraw from that part. It seems to have the same effect as disagreeable odors on men and animals. On the other hand, there are substances which attract, and into the water containing these they enter with eagerness. Strange is it, too, that, as proved by experiment, if an unattractive substance is used and also one on the other side that has been found still more unattractive, the less disagreeable is selected; the less of the two evils is chosen.

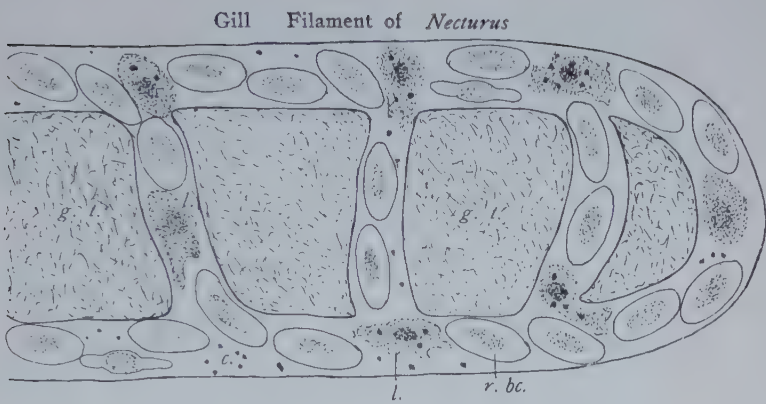
As man, the horse, dog, and many other animals adapt themselves gradually to temperatures either very cold or very warm, and that, too, by a change in their heat-regulating power rather than by a change of hairy or other clothing, so these lowly organisms are found in nature in water at temperatures from near freezing up to 60° or 80° C., a point approaching that of boiling water. It may be answered that each was created for its place, but by means of a microscope and a delicate thermostat, to be certain of every step and to see all the results, Dr. Dallinger, through a period of seven years, accustomed the same unicellular organism and its progeny to variations of temperature from 15° to 20° C., i. e., about the temperature of a comfortable sitting room, up to 70° C. For those at the cooler temperature it was death to increase rapidly the heat 10°, and for those at the higher temperature it was equally fatal to lower it to the original temperature of 15° to 20°. These examples seem to show that it is one of the fundamental characteristics of living substance, whether in complex or simple forms, to adapt itself to its environment.

There is another fact in nature that the microscope has revealed and that fills the contemplative mind with wonder and an aspiration to see a little farther into the living substance, and so perchance discover the hidden springs of action. This fact may be called cellular altruism. In human society the philanthropist and soldier are ready at any time to sacrifice themselves for the race or the nation. With the animals the guards of the flock or herd are equally ready to die in its defense.

So within each of the higher organisms the microscope has shown a guarding host, the leucocytes or white-blood corpuscles. The brilliant discoveries in the processes of life with higher forms have shown that not only is there a struggle for existence with dead nature and against forms as large or larger than themselves, but each organism is liable to be undermined by living forms, animal and vegetable, infinitely smaller

than themselves, insignificant and insidious, but deadly. Now, to guard the body against these living particles and the particles of dust that would tend to clog the system, there is a vast army of ameba-like cells, the leucocytes, that go wherever the body is attacked and do battle. If the guards succeed, the organism lives and flourishes; otherwise it dies or becomes weakened and hampered. This much was common scientific property three years ago, when one of our members, Miss Edith J. Claypole, came to my laboratory for advanced work. I discussed with her what has just been given, and told her that there still remained to be solved the problem, What becomes of the clogging or deleterious material which the leucocytes have taken up? These body-guards are, after all, a part of the organism, and for them simply to engulf the material would not rid the body entirely of it, and finally an inevitable clogging of the system would result. The problem is simple and definite: what become of the deleterious substances, bacteria and dust particles, that get into the body and become engulfed by the leucocytes? Fortunately for the solution of this problem, in our beautiful Cayuga Lake there is an animal, the *Necturus*, with external gills through which the blood circulates for its purification. So thin and transparent is the covering tissue of these gills that one can see into the blood stream almost as easily as if it were uncovered. Every solid constituent of the blood, whether red corpuscle, white corpuscle, microbe, or particle of dust, can be seen almost as clearly as if mounted on a microscopic slide. (See Plate XV.)

Into the veins of this animal was injected some lampblack, mixed with water, a little gum arabic and ordinary salt, an entirely nonpoisonous mixture. Thousands of particles of carbon were thus introduced into the blood and could be seen circulating with it through the transparent gills. True to their duty, the white corpuscles in a day or two engulfed the carbon particles, but for several days more the leucocytes could be seen circulating with the blood stream and carrying their load of coal with them. Gradually the carbon-laden corpuscles disappeared and only the ordinary carbon-free ones remained. Where had the carbon been left? Had it been simply deposited somewhere in the system? The tissues were fixed and serial sections made. The natural pigment was bleached with hydrogen dioxid, so that if any carbon was present it would show unmistakably. With the exception of the spleen, no carbon appeared in the tissues, but in many places the carbon-laden leucocytes were found. In mucous cavities and on mucous surfaces and on the surface of the skin were many of them; in the walls of organs were many more apparently on their way to the surface with their load; that is, the carbon is actually carried out of the tissues upon the free surfaces of the skin and mucous membranes, where, being outside of the body, it could no more interfere in any way with it. But what is the fate of the leucocytes that carry the lampblack out of the tissues? They carry their load out and free the body,



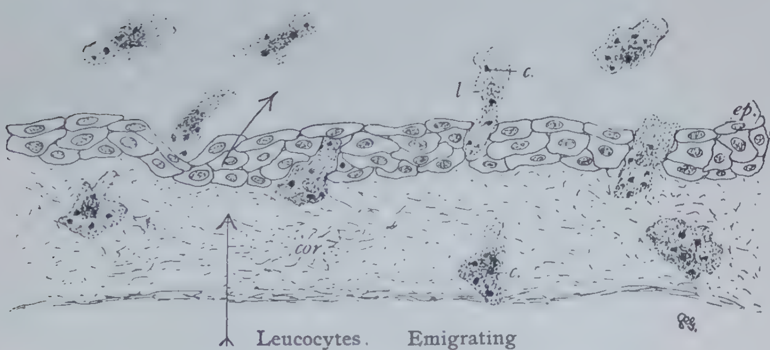


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FIG. 5. These figures represent various steps in the removal of foreign matter from the blood of *Necturus*.

Gill filament of *Necturus*.—Part of a single gill filament greatly magnified to show the blood vessels containing the red-blood corpuscles (*r bc*) and the leucocytes (*l*) or white-blood corpuscles. The black dots (*c*) within the blood vessels represent carbon particles which had been injected into the veins. In many of the leucocytes are several carbon particles; there are also several shown free in the blood plasma. *g t*. The tissue of the gill filament between the blood vessels.

Leucocytes emigrating.—This, the lower figure, represents a section of the skin with its covering, epithelium (*ep*), and the corium (*cor*) or true skin. The leucocytes containing carbon particles (*c*) are seen in the corium and penetrating the epithelium and finally free outside the epithelium. The arrows indicate that the leucocytes emigrate from the body through the corium and the epithelium, and finally into the space outside the epithelium.

but they themselves perish. They sacrifice themselves for the rest of the body as surely as ever did soldier or philanthropist for the betterment or the preservation of the state.

Thus I have tried to sketch in briefest outline some of the phenomena or processes of life revealed by the microscope. Most of those discussed have come under my own personal observation, and are therefore to me particularly real and instructive; but to every one long familiar with the microscope and with the literature of biology many other examples will occur, some of them even more striking. The discussion has been confined to the above also because it seems to me to show with great clearness the way in which we can justifiably hope to do fruitful work in the future. This sure way, it seems to me, is the study of structure and function together; the function or activity serving as a clue and stimulus to the investigator for finding the mechanism through which function is manifested, and thus give due significance to structural details, which, without the hint from the function, might pass unnoticed.

This kind of microscopical study may be well designated as physiological histology. It is in sharp contrast with ordinary histology, in which too often the investigator knows nothing of the age, state of digestion or of fasting, nervous activity, rest, or exhaustion. Indeed, in many cases it is a source of congratulation if he knows even the name of the animal from which the tissue is derived. Such haphazard observation has not in the past and is not likely in the future to lead to splendid results. If structure, as I most firmly believe, is the material expression of function, and the sole purpose of the structure is to form the vehicle of some physiological action, then the structure can be truly understood only when studied in action or fixed and studied in the various phases of action.

Indeed, if one looks only for form or morphology in the study of histology the very pith and marrow is more than likely to be lost.[1]

For example, if one wished to study the comparative histology of the pancreas, and were to take pieces from various animals to be compared without regard to their condition of fasting or digestion, he might find the coarser anatomical peculiarities in each. In all probability he would also find two dictinct structural types. One type with clearly-

[1]Although in a different field, the words of Osborn in discussing the unknown factors of evolution are so pertinent that they may well be quoted: "My last word is, that we are entering the threshold of the evolution problem, instead of standing within the portals. The hardest task lies before us, not behind us. We are far from finally testing or dismissing these old factors [of evolution], but the reaction from speculation upon them is in itself a silent admission that we must reach out for some unknown quantity. If such does exist there is little hope that we shall discover it except by the most laborious research; and while we may predict that conclusive evidence of its existence will be found in morphology, it is safe to add that the fortunate discoverer will be a physiologist" [armed with a microscope]. I would like to add the last four words. S. H. G. Am. Nat., May, 1895.

defined cells and nuclei, the other with the cells clouded, filled with granules and with the outlines of cells and their nuclei almost indiscernible. Between these there might be various gradations in the different forms. And yet, from what has been stated above, it is plain that all these different structural appearances represent phases of activity, and all might have come from the self-same animal. In like manner, if certain parts of the nervous system were to be studied comparatively, and the tissue taken from one animal after refreshing sleep and rest, from another after exhausting labor, another in infancy, and another from an animal decrepit with years, the difference in general appearance and in structural details would be striking enough to satisfy any morphologist that, as with the structure of the pancreatic cells, there were two or more distinct types; but the physiological histologist would recognize at once that the differences so much insisted upon represented different phases of activity, and, as with the pancreatic cells, might be all represented in the same animal at different times.

I would be far from saying that there are no structural differences in the different animals independent of any particular phase of functional activity; but if these only are sought and the others neglected the physiological appearances will often obtrude and confuse, if they do not utterly confound.

I have, therefore, for the last ten years urged my students, and mean to go on advocating with all the earnestness of which I am capable, that in studying an organism or its tissues, the investigator, to gain certain knowledge, must know all that it is possible to learn concerning the age, health, state of nervous, muscular, and digestive activity; in fact, all that it is possible to find out about the processes of life that are going on and have gone on when the study is made.

There are some microscopic forms in which the entire study can be made while the creature is alive. With the higher organisms, also, some of the living elements, as the white-blood corpuscles and ciliated cells, can be studied, and their various actions and structural changes observed for a considerable time.

The white-blood corpuscles or leucocytes resemble the amœba very closely in their actions and powers, as we have seen in discussing the way in which the body is freed from foreign particles. The ciliated cells are among the most striking of all the constituent elements of the body. One end is fixed firmly to the tissues, the sides are in contact with their fellow cells, but the other end is free and bears great numbers of hair-like processes, the cilia, which project freely into some cavity or upon some surface. What histologist would be able for a moment to suggest the power of these hair-like processes if he studied the dead cells alone? Yet the moment these cells are studied alive under the microscope it is seen that for the service of the body all the powers of these cells are concentrated into one, that of motion, and all the motion

is manifested by the little cilia. These sweep with almost incredible rapidity in one direction and more slowly on their return, thus producing a current in the direction of most rapid motion. This motion with the resulting current ceases only with life. Each individual cilium is weakness itself, but with their combined action the untold millions covering the cells, in the air passages for example, make a strong current in the liquid covering them. This current is from the interior of the lungs toward the throat and carries along with it particles of dust inhaled into the lungs. In this way the delicate breathing organs are swept clean and left unincumbered for their work of receiving oxygen and getting rid of carbon dioxide.

If now one puts under the microscope some cells from the small intestine of almost any animal from the lamprey eel to man, the cells appear almost identical with those just described. The end projecting to the free surface of the intestine seems to have a similar brush of fine hairs, with a clear line along their base. If a striated and a dead ciliated cell are under the same microscope side by side, it is almost impossible to distinguish them. Indeed so difficult is it that those from the intestine have been described as ciliated more than once. If both cells are living, no one could confuse them. The striated end of one is motionless, the lines or cilia of the other are in constant motion. One serves for producing currents, always in the same direction, the other is for the purpose of absorbing and passing into the tissues the products of digestion. One is a moving the other an absorbing cell. (See Plate XVI.)

Most of the tissue elements of the higher forms can not be thus studied alive, however, and the best that can be done is to fix the different phases of action, as by a series of instantaneous photographs, then with a kind of mental kinetoscope put these together and try to comprehend the whole cycle.

Fortunately for the histologist the incessant experimentation of the last twenty-five years has brought to knowledge chemical substances which do for the tissues the wonder that was ascribed to the mythical Gorgon's head—to kill instantly and to harden into changeless permanence all that gazed upon it. So the tissues may be fixed in any phase and then studied at length. If then the investigator observes and keeps record of every point that may have an influence on the structural appearances, whether shown by experience or suggested by insight, and this record always accompanies the specimen, thus and thus only, it seems to me, can he feel confident that he is liable to gain real knowledge from the study, knowledge that represents actuality, and which will serve as the basis for a newer and more complete unraveling of the intricacies of structure, an approximate insight into the mechanism through which the life energy manifests itself.

And so, with all the life that physics and chemistry can give, commencing with the simplest problems and being careful that every factor

that can influence the result is being duly considered, the microscopist can go forward with enthusiasm and with hope, not with the hope that the great central question can be answered in one generation, perhaps not in a thousand, but confident that if each one adds his little to the certain knowledge of the world, then in the fullness of time the knowledge of living substance and the life processes will be so full and deep that what life is, though unanswered, may cease to be the supreme question.

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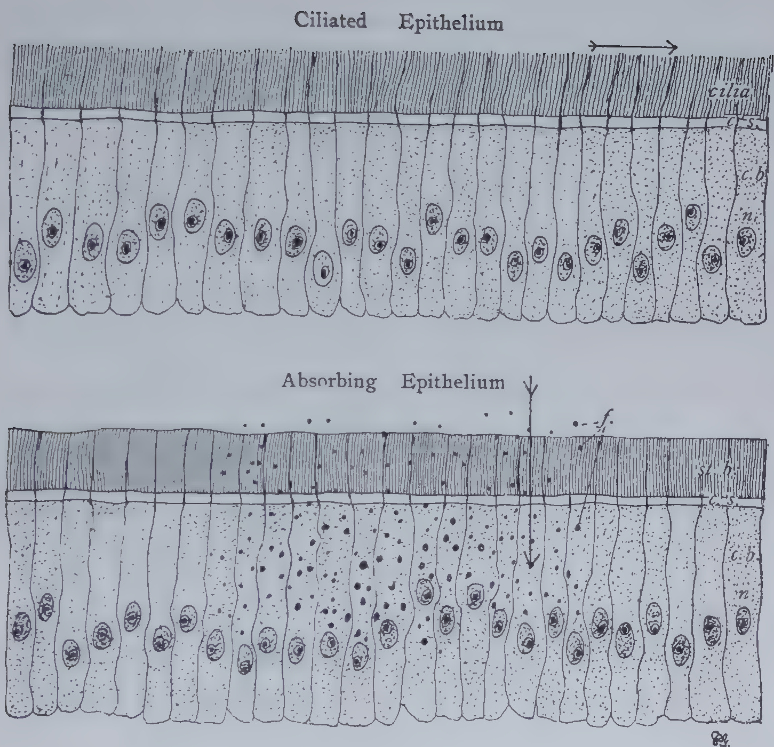

PROCESSES OF LIFE REVEALED BY THE MICROSCOPE.

FIG. 6. Figures showing the similarity in appearance of the absorbing epithelium of the intestine and of a ciliated epithelium. The free ends of the cells point upward toward the top of the page, and the attached ends toward the bottom of the page. *cilia*, The minute, hair-like processes projecting from the free end of the cells and constantly swinging rapidly in one direction and returning less rapidly to the starting point. In this way a current is made in the direction of the most rapid motion (indicated by the arrow). At the base of the cilia is a clear plate or segment (*c s*).

In the absorbing epithelium the segment appearing like the cilia is called the striated border or segment (*st b*) and rests on a clear segment (*c s*) comparable with that on which the cilia rest. In the absorbing epithelium food particles (*f*) are represented as passing through the cell from the free end toward the base, as indicated by the arrow.

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THE GENERAL CONDITIONS OF EXISTENCE AND DISTRIBUTION OF MARINE ORGANISMS.[1]

By Dr. JOHN MURRAY,
of Edinburgh.

Since the great geographical discoveries at the end of the fifteenth and the beginning of the sixteenth centuries which are associated with the names of Columbus, Da Gama, and Magellan, there have been no additions to the knowledge of the surface of our planet that can in any way compare with those which have resulted from the exploration of the great ocean basins during the past quarter of a century. The French, the Germans, the Americans, the English, the Norwegians, the Italians, the Swedes, the Austrians—indeed, nearly all civilized nations—have taken part in these explorations, and the result has been a vast accumulation of new observations and new facts.

Whenever science is enriched by a large number of new observations in new regions a change almost invariably follows in our theoretical conceptions. Indeed no complete theory of the earth was possible so long as we were ignorant of the three-fourths of the earth's surface covered by the waters of the ocean. We are very far from having anything like a complete knowledge of the physical and biological conditions of the ocean, but we know very much more than we did thirty years ago, and it is to some of these additions to our knowledge of the ocean that I propose to direct your attention to-day, especially those having a more or less direct bearing on biology.

The observations themselves are good for all time. The deductions I may draw from them may be erroneous and evanescent, still it may be interesting to you to catch some glimpse of how one who has spent over twenty years in the study of oceanic phenomena has been cutting paths through the almost impenetrable forest of observations that has grown up in recent years.

Although we have still no accurate knowledge of the depth over large areas of the ocean, yet deep-sea soundings have in recent years become so numerous that it is probable the contour lines laid down on the most recent maps will not be greatly altered, so far as their general

[1] From Société Néerlandaise de Zoologie. Compte-Rendu des Séances du Troisième Congres International de Zoologie. Leyde. 16-21 Septembre, 1895. Leyde: E. J. Brill, 1896, pp. 99–111.

position is concerned, by future investigations. Quite recently a depth of over 4,900 fathoms (nearly 9 kilometers) has been recorded in what is known as the Aldrich Deep, to the southeast of the Friendly Islands; the greatest depth at which bottom has been reached is in 4,660 fathoms (8½ kilometers) in the Atlantic, north of the Virgin Islands. A nearly equal depth—4,655 fathoms—is found in the Tuscarora Deep, to the east of Japan. The *Challenger's* deepest sounding was in 4,475 fathoms (over 8 kilometers), north of the Caroline Islands. On the whole I estimate that about 5 per cent of the area of the ocean has a depth of over 3,000 fathoms (5½ kilometers).

The whole surface of the earth may, from a quite general point of view, be divided into elevated plateaus and submerged plains, the elevated plateaus being represented by the continents, which occupy about two-sevenths of the earth's surface, and the submerged plains by the abysmal areas of the ocean, which cover about four-sevenths of the earth's surface, the remaining one-seventh of the earth's surface being occupied by the slope connecting the one with the other. The average level of the continental plateaus is about 2,500 fathoms (over 4½ kilometers) above the general level of the abysmal area. These great troughs or hollows on the surface of the earth are filled with salt water up to within a few hundred feet of the average height of the continental plateaus.

At the present time the temperature of the ocean water varies from 28° or 29° F. (—2.22° or —1.67° C.) at the poles to from 80° to 85° F. (from 26.67° to 29.44° C.) at some points within the tropics. The seasonal variation of the surface temperature is not felt at depths over 100 fathoms. At the level of a depth of 1,000 fathoms beneath the surface the mean temperature of the ocean is 36.5° F. (2.5° C.), the Atlantic and Indian Oceans being, on the whole, warmer than the Pacific at this depth, and at greater depths, even within the tropics, the temperature may at some points fall as low as the freezing point of fresh water.

Sea water contains in solution a fairly constant proportion of salts and a more variable proportion of gases. The saline constituents, to which sea water owes its distinctive properties, consist chiefly of chlorides and sulphates, with a comparatively small, but none the less important, proportion of carbonates and bromides. Of some twenty-four metals which have been detected in sea water, only sodium, magnesium, calcium, and potassium are of any importance in determining the character of the water. The presence of this saline matter gives the water an increased density, and this density, measured under uniform conditions, is taken as a measure of the absolute quantity of salt in solution.

In any sample of sea water the proportions of the various saline constituents remain quite sensibly constant among themselves. This statement, although true as a rule, is liable to an exception in the case of lime, for, from actual determinations of the lime and from the increase

in the alkalinity of very deep waters, there seems to be no doubt that the quantity of lime increases with the depth. It has long been known that sea water is distinctly alkaline to test paper; this is due to an excess of base over sulphuric and hydrochloric acids, the surplus base being more or less saturated by carbonic acid, too weak an acid to bring about a neutral reaction.

The gases in sea water are not only much more variable than the saline matters in their absolute amount, but also vary in the proportions among themselves. The gases of general occurrence are oxygen, nitrogen, and carbonic acid, the two former being wholly derived by absorption from the atmosphere, while the last named is partly absorbed from the atmosphere and partly due to excretion from animals and to oxidation of organic matter in situ.

The gas is absorbed from the atmosphere by the merest surface layers only of the water, and is distributed to the rest of the ocean by descending currents. The quantity absorbed is determined by the temperature of the water and the pressure of the atmosphere, but chiefly by the former. If the water remaining on the surface pass to a warmer region gas is given off, if to a colder region more is absorbed. Once the water is cut off from the surface by overlying layers of water all further absorption of gas ceases. Of the three gases nitrogen alone remains constant in quantity. The oxygen of the water is taken up by animals for the furtherance of their metabolic processes, and in i's place they excrete carbonic acid. Thus, if free surface ventilation be denied there is a continual decrease in the proportion of oxygen and a corresponding increase in the quantity of carbonic acid; and in small inclosed seas this process may go so far as to render the water quite unfit for the support of animal life of any order much higher than that of bacteria.

On account of the coefficient of absorption of oxygen being double that of nitrogen, the proportion of oxygen to the total gas in sea water under full aeration is double that in air, being as a matter of fact $34\frac{1}{2}$ to $33\frac{1}{2}$ per cent. The absolute quantity of gas in solution in surface waters is found to decrease as we go from the poles to the equator, as also does the proportion of oxygen. In high latitudes, indeed, the proportion of oxygen is so high as to amount to supersaturation, as much as 36.7 per cent having been found in polar waters. The quantity of oxygen is always less in bottom than in intermediate waters from great depths, but no oceanic water at least is found to be absolutely devoid of oxygen, although in waters from the bottom in great depths the amount is sometimes very small.

Both the horizontal and vertical circulation of ocean waters is mainly governed by the prevailing winds which blow over the surface, and these are again determined by the position of the areas of high and low barometric pressure. Where the winds are dry and constant there we find the saltest water at the surface, as for instance in the trade-wind regions of the North and South Atlantic and South Pacific,

where the salinity is over 1.027; but in the inclosed basins of the Mediterranean and Red seas the salinity may reach 1.030. The average salinity at the surface in the open ocean is higher than on the bottom, and, like the temperature, is higher at the bottom in the Atlantic and Indian Oceans than in the Pacific.

The density of ocean water is dependent upon temperature as well as pressure, and in consequence the less saline water of the polar regions has a higher density than the salter waters of the tropics, and in general the lowest annual and diurnal temperatures tend to be propagated downward to the greater depths. Vertical circulation downward is likewise to some extent determined by the presence of detrital matter from rivers, and by the action of very constant winds like those which prevail over the great Southern Ocean.

When we examine the deposits now being laid down on the floor of the ocean, we find that in all inclosed basins surrounded by continental land, and for an average distance of 200 miles off continental shores facing the great oceans, the deposits are for the most part made up of detrital matters more or less directly derived from the subaerial denudation of the dry land, or as a result of the destructive action of waves and currents in the shallow regions of the ocean. Even when such deposits are composed for the most part of carbonate of lime organisms, such as shells, corallines, and corals, these bear the impress of the mechanical action of the forces at work in the shallow waters, and are therefore included under the general term of terrigenous deposits. The predominant mineral in these terrigenous deposits is quartz, being in many positions associated with glauconite; and both these minerals appear to be almost wholly absent in the central parts of the great ocean basins, except where the surface waters may be affected by floating ice.

The alkalies, alkaline earths, iron, manganese, and other bases, at one time associated with the quartz of the sand dunes, sandstones and other rocks of the continents, have been separated by chemical decomposition, and carried in solution or in suspension out into the abysmal regions of the ocean, where they have accumulated through physical or organic agencies. The lighter, less soluble, and more refractory quartz has, on the other hand, accumulated on the continents and in the deposits in their immediate vicinity. If this process has been going on continuously since precipitation of water first took place on our planet, the rocks on the continental areas would become more and more acid in constitution and lighter, while the deposits formed at the bottom of the ocean would become more and more basic and heavier. The reason why the continents on the whole stand at a higher elevation than the floor of the ocean basins may well be that, by this continuous process, they are the lighter portions of the superficial crust, as is indeed indicated by the general results of pendulum and plumb-line observations.

In the terrigenous deposits now being laid down in the shallow and deep waters of the continental areas, we have in the organic remains quartz, glauconite, phosphatic nodules, an assemblage of materials resembling in all important respects the stratified layers making up the larger part of the continental masses.

When we turn to the deposits in the abysmal regions far removed from continental land we find that deposits are being formed which do not resemble so closely the continental rocks. In depths of less than 2 miles the deposits are principally made up of the dead shells of carbonate of lime secreting organisms, which had lived at the surface of the sea, such as calcareous algæ, foraminifera, pteropods, and other pelagic mollusks, forming globigerina and pteropod oozes. In the colder parts of the extratropical regions the siliceous frustules of diatoms which had lived on the surface predominate in the deposit, and thus produce a diatom ooze. In the still greater depths of the ocean, i. e., over 2 miles, the carbonate of lime organisms are partially or wholly removed, either while falling to the bottom or shortly after reaching the bottom, through the solvent action of the sea water. Where they are wholly removed the deposit may, as, for instance, in the western parts of the Pacific, contain a considerable percentage of radiolarian skeletons, which had lived in the surface and intermediate waters, and the deposit is then called a radiolarian ooze, but usually the deposit is what has been called a red (or chocolate-colored) clay, and this covers a larger proportion of the sea bed than any other kind of deposit.

The red clay has evidently accumulated at an extremely slow rate. It consists principally of hydrated silicate of alumina and the peroxides of iron and manganese, mixed with thousands of sharks' teeth, represented by the dentine of *Carcharodon*, *Lamna*, and *Oxyrhina*, of dense ear bones of various species of cetacea, and the dense mesorostral bones of ziphioid whales. These red-clay deposits likewise contain many magnetic spherules with crystalline or metallic nuclei, which are believed to be the dust burnt off from the outer surfaces of meteoric stones heated as they pass through our atmosphere. These cosmic spherules probably fall all over the surface of the earth, but their presence is here evident because the deposit may not accumulate to the extent of more than an inch in several centuries. The manganese and the iron are often deposited in concentric layers around the sharks' teeth, ear bones, and volcanic lapilli, and in some places the deposit contains many zeolitic minerals which have evidently been formed in situ.

When we turn to the observations on the pelagic fauna and flora it will be found that there is a considerable difference between the organisms observed near shore and those present in the open regions of the ocean—a difference recognized in the terms neritic and oceanic plankton. The coccospheres, rhabdospheres, pelagic foraminifera, heteropoda, pteropoda, and radiolaria, so abundant in tow net gatherings in

the open ocean, are absent or but sparingly represented in tow-net gatherings near the land.

All the carbonate of lime secreting organisms are much more abundant in the warmer than in the colder waters, and we have seen that their dead shells are much more abundant at the bottom within the tropics than toward the polar areas; indeed, through these organic processes the lime present in solution in the ocean, probably in large part originally derived from the disintegration of the continental rocks, is at the present time being accumulated toward the tropical regions of the earth. In the Tropics there are in the surface waters over twenty species of pelagic foraminifera which secrete thick carbonate of lime shells. These mostly disappear as the colder waters of the polar regions are approached, and are there represented by two dwarfed species of globigerina. In the same way many species of shelled pteropods, heteropods, and pelagic gasteropods live in the warmer waters of the tropics, but disappear or are represented only by small thin-shelled limacinæ or naked species in polar waters. The calcareous coccospheres and rhabdospheres of the tropical and warm waters give place in polar waters to species of algæ which secrete no lime.

This abundant secretion of carbonate of lime in the warm waters of the Tropics is apparently due to chemical rather than physiological conditions. When neutral ammonium carbonate is added to sea water at a high temperature—80° to 85° F.—the lime salts other than carbonate present in sea water are quickly decomposed and an immediate precipitate of carbonate of lime having the properties of aragonite is formed, while if the same experiment be carried out at a low temperature—40° to 45° F.—the carbonate of lime separates out very slowly and in doing so takes the form of calcite. The abundant secretion of carbonate of lime in the warm waters of the Tropics at the present day, as well as the feeble development of carbonate of lime organisms in cold polar regions, are interesting facts when we remember that coral reefs flourished within the Arctic Circle during Palæozoic and even later times, and from the manner in which the lime is secreted we may safely conclude that the polar waters in these ancient times must have had a temperature of about 70° F. (21° 1 C.).

Not only is the number of species of lime-secreting organisms in the surface waters of the Tropics greater than in the cold water of the polar regions, but the same holds good for the radiolaria and nearly all other classes of pelagic organisms, the characteristic of the pelagic organisms of the polar areas being a relatively small number of species and a great abundance of individuals. Another peculiarity of the tow-net gatherings in the Arctic and Antarctic areas is the almost complete absence of pelagic larvæ of benthos animals, which are so abundant in the surface waters of the Tropics. A comparison of two tow-net gatherings conducted under precisely similar conditions, one in the cold waters of the Antarctic and the other in the warm waters of the Tropics,

shows that there is a much greater number of species in the Tropics than in the Antarctic, but at the same time a less total amount of organic matter, due to the smaller absolute number of individuals in the warmer waters. In making this comparison, however, it must be recalled that the metabolism of cold-blooded animals rises with the temperature of the water, and is therefore very much more rapid within the Tropics than at the Antarctic Circle, so that within a given period of time many more organisms may pass through their life history in warm than in cold water, but on account of the high temperature of the water the effete products are more rapidly disposed of than in the cold polar waters, where chemical action is more sluggish. A measure of this rate of change is to be found in the large amount of saline ammonia present in the sea water of the Tropics, while albuminoid ammonia predominates in polar waters.

When we compare the shallow-water animals living on or attached to the bottom within the tropics and toward the polar regions, we find that the distribution follows the same laws as in the case of the pelagic organisms. There are many more species, especially of lime-secreting organisms, in the warm waters of the tropics than in the colder waters toward the poles. For instance, the *Challenger's* dredgings in the vicinity of Cape York, Australia, in depths less than 12 fathoms, yielded 554 species of metazoa, while many more dredgings at Kerguelen, in depths less than 25 fathoms, yielded only 130 species; indeed the total number of species known from Kerguelen in depths less than 25 fathoms amounts only to 242 species. While the number of species of shell-bearing mollusks procured by the *Challenger* in depths less than 12 fathoms at Cape York was 292, only 92 species were taken at Kerguelen down to 120 fathoms, and the total number known from Kerguelen is only 125 species. The higher crustacea (macrura, anomura, brachyura) are also more abundant in the tropics, while the reef-building corals are, of course, entirely absent at Kerguelen. On the other hand, the hydroida, holothurioidea, annelida, amphipoda, isopoda, pycnogonida, and tunicata, which secrete little or no carbonate of lime, are more numerous in the cold waters around Kerguelen.

The recent deep-sea researches have shown that not only is life universally present in great abundance at the surface of the sea, and probably also, though much more sparsely, in all the intermediate depths of the ocean, but also that fishes and all the invertebrate groups are spread all over the floor of the ocean in great numbers. The total number of species taken by the *Challenger* in depths less than 100 fathoms is 4,400; in depths between 100 and 500 fathoms, 2,050; in depths between 500 and 1,000 fathoms, 710; in depths between 1,000 and 1,500 fathoms, 600; in depths between 1,500 and 2,000 fathoms, 500; in depths between 2,000 and 2,500 fathoms, 340, and in depths over 2,500 fathoms, 235. It is thus seen that the actual number of species procured decreases with increase of depth, and if we take into

account the number of stations included in each zone of depth we find that the number of species per station decreases gradually from 62.8 species per station in the shallowest zone to 9.4 species per station in the deepest zone, as shown in the following table:

Depth in fathoms.	Species per station.
Under 100	62.8
100 to 500	51.2
500 to 1,000	30.9
1,000 to 1,500	24.0
1,500 to 2,000	15.6
2,000 to 2,500	10.6
Over 2,500	9.4

Again, it is interesting to point out that the proportion of genera to species procured in the different zones increases gradually with increase of depth, the ratio of genera to species in the shallowest zone being as 1 to 2.93 and in the deepest zone as 1 to 1.17, as shown in the following table:

Depth in fathoms.	Ratio of genera to species as—
Under 100	1 to 2.93
100 to 500	1 to 2.37
500 to 1,000	1 to 1.67
1,000 to 1,500	1 to 1.50
1,500 to 2,000	1 to 1.45
2,000 to 2,500	1 to 1.36
Over 2,500	1 to 1.17

An analysis of dredgings at similar depths close to and far removed from continental shores shows that both species and individuals are more numerous on the terrigenous deposits close to the shore, and the proportion of species to genera is higher, than on the pelagic deposits far removed from the land. This seems to indicate that migration has taken place from the shallow waters close to the shore to the deeper waters of the great ocean basins, and that the ancestors of the fauna at great depths far removed from land have migrated from many shallow-water areas on the surface of the globe. On the whole the deep-sea fauna resembles that of the shallow waters of the polar regions much more than that of the shallow waters of the tropical regions, in so far as the animals of the deep-sea fauna have a relatively small quantity of carbonate of lime in their shells and skeletons, the proportion of genera to species is higher than in the tropics, and there is an absence of pelagic or free swimming larvæ.

In depths of over 1,000 fathoms the *Challenger's* trawlings rarely yielded over 10 or 15 specimens of any one species, but in lesser depths,

for instance in about 500 fathoms, hundreds of specimens of holothurians, pycnogonids, and crustaceans have been procured in a single haul, and just beneath the mud line at a depth of about 100 fathoms around continental shores enormous numbers of individuals belonging to one species have been procured. This is the great feeding ground in the ocean. To this depth the herring, salmon, whales, narwhals, descend to feed upon the immense numbers of individuals belonging to species of *Calanus*, *Euchæta*, *Passiphæa*, *Crangon*, *Hippolyte*, as well as species of schizopods, amphipods, isopods, fishes, and cephalopods.

Probably the majority of deep-sea species live by eating the surface layers of the mud, clay, or ooze at the bottom, and by catching or picking up the small organisms, or minute particles of organic matter which fall from the surface or are washed away from the shallower reaches of the ocean, and ultimately settle on the bottom beyond the mud line. These mud-eating species are in turn the prey of numerous rapacious animals armed with peculiar tactile, prehensile, and alluring organs, for phosphorescent light plays an important rôle in the economy of deep-sea life, and is correlated with the red and brown tints of the majority of deep-sea organisms. Some species are blind, and others, in addition to large eyes, are provided with a sort of bull's-eye lantern, from which streams of light are thrown out at the will of the animal. Phosphorescent organs act sometimes as a lure, sometimes they indicate the presence of prey or the passage of an enemy.

Some species of deep-sea organisms are of gigantic size when compared with their shallow-water allies. Some of the hexactinellids are 3 or 4 feet in diameter; the hydroid *Monocaulus* is 3 feet in height; the legs of some pycnogonids extend for over a foot on either side of the body, and the largest echini and isopods are found in deep water.

Before the systematic investigation of the deep sea it was believed by some naturalists that the remnants of faunas which flourished in remote geological periods would be found in the great depths of the ocean. This expectation has not been realized. *Discina* and some other brachiopods undoubtedly represent a very ancient group; still the king-crabs, lingulas, trigonias, Port Jackson sharks, *Heliopora*, *Amphioxus*, *Ceratodus*, *Lepidosiren*, and other shore and shallow-water forms undoubtedly represent older forms than anything to be found in the deep sea at the present time.

Sir Wyville Thomson was of opinion that from the Silurian period to the present day there had been, as now, a continuous deep ocean, with a bottom temperature oscillating about the freezing point, and that there had always been an abyssal fauna. It is much more probable that in palæozoic times the ocean basins were not so deep as at the present time; that the ocean had then a nearly uniform high temperature throughout its whole mass, and that life was either absent throughout all the greater depths or represented only by bacteria, as in the Black Sea at the present day.

An analysis of the *Challenger's* results seems to show that the deep-sea organisms at present inhabiting the sea bed are not, as is generally supposed, universally distributed in the abysmal area; indeed, they do not seem to be much more widely distributed than shore forms from any one given region. Of the 272 species taken in the deep-water area of the Kerguelen Region, in depths of over 1,260 fathoms, 60 per cent are only known from these dredgings, and not more than 6 per cent have been found in the dredgings within and to the north of the tropics. Again, of the 523 species found in depths over 1,000 fathoms south of the southern tropic, 64 per cent are known only from this area, and only 8 per cent are known from dredgings within the tropics and to the north of the northern tropic.

The *Challenger* dredgings in the neighborhood of Marion, Kerguelen, and Heard islands, down to a depth of 150 fathoms, gave 533 species; of these 61 per cent are unknown outside that region, while 3 per cent are known from areas within and to the north of the tropics, and 6 per cent are known from regions north of the northern tropic, but not within the tropics. I have already stated that the number of genera and species is largest in the shallow zone under 100 fathoms, and that the number decreases down to the deepest water far removed from land. This relation apparently holds good even in shallower depths less than 100 fathoms, and especially within the tropics, the number of genera and species in depths less than 20 fathoms on the whole exceeds the number in deeper water. The statistics of the *Challenger* investigations in the neighborhood of Kerguelen, however, seem to show that in depths less than 50 fathoms the number of species and genera may be less than in greater depths, for the total number of species recorded from Kerguelen in depths less than 50 fathoms amounts to 242, less by 30 species than the number captured in 8 trawlings in depths greater than 1,260 fathoms, and in depths between 75 and 150 fathoms around these Antarctic islands both species and individuals appeared always to be more abundant than in shallower water.

The general similarity between the fauna and flora of high northern and high southern latitudes has been many times remarked, and in the first dredgings of the *Challenger* in comparatively shallow water in the southern hemisphere the naturalists were very much struck by the character of the fauna being very like what they had been accustomed to procure in somewhat shallower water off the northern coasts of Europe; the species in many cases seemed to be identical. This impression was deepened as the *Challenger* dredgings still further to the south were examined. The specialists who have described the various groups of animals brought home by the *Challenger* frequently call attention to species from the Kerguelen Region being identical or closely allied to species occurring in the far north, which at the same time are wholly unknown from within the tropics. We are now acquainted with about 150 identical species of Metazoa, and nearly 100 closely allied species,

occurring in the extra-tropical regions of the northern and southern hemispheres, and wholly unknown from the intervening tropical zone. Again, a list has recently been published giving 54 species of marine Algæ common to the northern and southern oceans, and not occurring within the intervening tropical belt.[1] In fact, the arctic and antarctic marine faunas and floras, geographically as wide asunder as the poles, are generally more closely related to each other than to any intervening fauna or flora. This is all the more remarkable when we remember that, with the exception of a few pelagic, brackish water and deep sea species, there is hardly a species of marine Metazoa common to the east and west coasts of Africa within the tropics.

In order to give a rational explanation of these remarkable facts in the distribution of marine organisms at the present time, as well as of the presence of tropical fossils in Paleozoic and even later geological strata within the polar areas, it seems necessary to assume that at one time there was a very different distribution of heat and light over the surface of the globe than what obtains at the present time. A uniform high temperature all over the surface of the globe in the early stages of the earth's history is required to explain these phenomena. In later Mesozoic times a gradual cooling at the poles appears to have set in, and slowly brought about the destruction of a large number of the shore and shallow-water animals, especially those which secreted large quantities of carbonate of lime or were provided with pelagic or free-swimming larvæ. This weeding out of numerous species in the polar areas, from a fauna which must have much resembled the coral-reef fauna of the present time, accounts for the relatively small number of species which we now find in polar waters, and, through lessened competition, for the relatively large number of individuals belonging to some of these species. In still later times, when polar lands became covered with ice and snow and when glaciers descended at almost all points into the ocean, shallow-water organisms appear to have taken refuge in the deep sea, and a migration of polar animals toward the equator was initiated over the floor of the ocean. This may account for the relatively more abundant fauna in the great depths of the Southern Ocean, as indicated by the *Challenger's* investigations. The large numbers of pelagic animals which are continually being killed through the mixture of surface currents of different origins between latitudes 40° and 50° south, falling to the bottom, provide an abundant supply of food for deep-sea animals, and the large quantity of oxygen taken down by descending currents from the cold surface waters produces further favorable conditions of life in these great depths.

In discussing the causes of the distribution of organisms over the surface of the earth at the present time, or the geographical distribution of fossils in Paleozoic rocks, it is too often assumed that the relations

[1] Murray and Barton. Phycological Memoirs from the British Museum, London, 1895.

between the earth and the other members of the solar system were in past times the same as we now find them. The variation in the astronomical elements of the globe is so small that they are regarded as stable for the period covered by history, but this variation assumes great importance when the periods represented by geology are brought into consideration.

Lord Kelvin says the nebular theory of the evolution of the solar system, "founded on the natural history of the stellar universe, as observed by the elder Herschel and completed in details by the profound dynamical judgment and imaginative genius of Laplace, seems converted by thermodynamics into a necessary truth if we make no other uncertain assumption than that the materials at present constituting the dead matter of the solar system have existed under the laws of dead matter for a hundred million years."[1] A large sun during the early stages of the earth's history is therefore a necessary result of what is believed to have been the genesis of our system. The earth is an extremely small fragment thrown off from the central sun at one of its periods of condensation, and by reason of its small dimensions its stellar phase would be comparatively short. On the other hand, the enormous mass of the sun would cool much more slowly, and its gradual contraction would provide an amount of energy sufficient to make good all that lost in radiation.

We may well suppose that when the sun had a diameter little less than the diameter of the orbit of Mercury the precipitation of water, geological and life phenomena, commenced on our earth.[2] Such a nebulous sun would radiate for each unit of its surface less heat and light than the sun at present, but the total amount of radiant energy received by the earth might be greater than that received at present, and would be very differently distributed over the earth's surface. The Torrid Zone would be extended on either side of the equator to the forty-seventh parallel of latitude. The seasonal effects produced by the inclination of the earth's axis to the ecliptic would be annulled. There would be suppression of a twenty-four-hour night about the poles at any time of the year. A cone of effective solar rays would graze the earth along a small circle of the sphere; at the solstice the rays of light would touch one pole and envelop the other to the forty-third parallel of latitude, so that at this position of the earth four degrees of latitude—those between 43° and 47°—would have at the the same time a twenty-four-hour day and some portion of the sun overhead at noon. A sun the angular diameter of which is equal to twice the obliquity of the ecliptic, i. e., 47°, would thus produce at the poles during the whole year an insolation 18 per cent greater than at

[1] Kelvin. Popular Lectures and Addresses, Vol. I, pages 421-422. London, 1891.

[2] "Les géologues pourront trouver, dans le diamètre considérable de la masse solaire à ces époques, l'explication de l'égalité de climat dont paraît avoir joui la terre jusqu'au commencement de l'époque actuelle." (Wolf. Les Hypothèses cosmogoniques, page 32. Paris, 1886).

present, tending to a complete uniformity of climate over the earth's surface.[1] When we take into consideration the effect of the earth's atmosphere, a sun with a diameter even half that here indicated would account for the paleothermic phenomena made known by the records of the past life on the globe. When seeking a rational explanation of the gradual evolution of the surface features of the globe, it is necessary to take into account the contemporaneous evolution of the other members of the solar system, and especially that of the central luminary.

[1] Blandet. Bull. Soc. Geol. de France, Tom. 25, p. 777, 1868.

THE BIOLOGIC RELATIONS BETWEEN PLANTS AND ANTS.[1]

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In the study of natural sciences it is often an excellent plan to begin by stating a well-worn truism. To say, in the present state of our knowledge, that close relations exist between plants and insects is to utter such a truism.

At the close of the last century the wonderful discoveries of Koelreuter followed by those of Sprengel had already demonstrated such relations. It was upon the teachings of that genial thinker that was built a great part of the theory of selection given definitive form by the labors of Darwin. At that period, however, the relations between plants and insects, even when viewed by the light of evolution, were considered almost solely with regard to the cross-fertilization of vegetable organisms. The biologic relations between plants and ants have been fully examined only by our contemporaries. Though the topic is one of extraordinary fecundity, it is but little known to the general public.

Among the subjects that biology offers for our consideration some are especially fortunate in that their exposition requires no personal talent, their interest depending upon a mere recital of facts. One of these privileged subjects is the relations of plants and ants, and this selfish consideration has led me to choose it for my remarks.

As a preliminary to the study of the relations of ants to living vegetable forms it will be well to rapidly examine the organs that insects use in establishing such relations. We need not dwell upon their legs, which are very movable and constructed upon the general plan of the legs of insects. The claws that terminate them are used by ants in clinging to rough surfaces, in scratching the ground, in rejecting refuse, in holding food. Between the claws are found very delicate organs, the pulvilli, by whose aid the insect can cling to smooth surfaces, whether vertical or horizontal, against the force of gravity, by means of an oily secretion that causes the foot to adhere by capillary

[1]Translated from the Compte Rendu de la 24me Sess. de l'Association Française pour l'Avancement des Sciences, 1895, prémière partie, pp. 31–75.

attraction. Upon the head of an ant are borne sense organs—compound and simple eyes, organs apparently olfactory in character, antennæ, and buccal organs. On either side of the buccal opening are two large chitinous pieces, triangular in shape, articulated so that they can be moved apart or toward each other in a horizontal direction like the two jaws of a pinchers, the surfaces in contact being usually cut like a saw. These mandibles have a most important office, serving both as a weapon and as a tool. They are, in fact, used as scissors for cutting, as pinchers for dragging or tearing, as a trowel is in tempering and laying on mortar, as a shovel for removing excavated matter. It might almost be said that the only use for which they are absolutely unfitted is that of mastication of food. Below and behind them are found the maxillæ, formed by three coarticulated pieces, movable, membranous in character, bearing on their surfaces several rows of hairs and gustatory papillæ. Like the mandibles, they can not serve in mastication, but they assist the lips and the palpi in the recognition and seizure of food. The maxillæ bear the maxillary palpi, composed of from one to six pieces, organs especially tactile. The labrum, usually concealed under the epistoma, forms the anterior wall of the buccal opening. It is a flattened piece of variable form, often bilobate, capable of movement from behind forward in a horizontal plane. The lower lip forms the floor of the mouth and carries the ligula, an extensible piece which, because of its mobility, may be used for lapping or licking up fluids. The rows of gustatory papillæ that it carries in front and behind are the principal seat of the sense of taste. On each side of the lower lip are inserted the labial palpi, usually smaller than the maxillary palpi, formed of from one to four pieces. These also are tactile organs. According to Forel the mandibles are never used for eating. The most attentive observations confirm this, and the disproportion between the mandibles and the maxillæ makes it evident. The mandibles remain closed and immovable while the ant is eating. The mouth is usually closed by the labrum, which is turned over it, downward and backward, covering entirely the anterior part of the maxillæ and of the lower lip. When the ant wishes to eat it makes a complex movement of the pharynx which pushes forward the ligula, together with the neighboring parts, raising the labrum like a lid. The maxillæ are too short and too weak to crush a solid; they can only draw into the mouth a liquid or semisolid. It is the ligula or tongue which is most used by ants when they eat, and, according to the apt expression of Lespés, they use it as a dog does when he laps. When the ants are dealing with a solid body inclosing a liquid they first tear it with their mandibles and then lap up its contents. The buccal apparatus can, then, be used for scraping, cutting, and licking.

Mention should be made of the apparatus for the production of venom. This is situated on the posterior part of the abdomen and, as we shall hereafter see, may render to plants, the friends of our insects, certain

indirect services. Its essential parts are a double, paired gland and a single unpaired gland, there being secreted by one of these, as is probably the case with all the hymenoptera, an acid liquid, while the secretion of the other is alkaline. From the admixture of these is formed a true acid venom whose irritating property is partly due to the presence of formic acid. This venom is discharged into an inoculating apparatus developed in a greater or less degree in different species. The pain produced by the bite of indigenous species of ants is but slight, but exotic species may cause suffering of considerable intensity and duration.

This rapid review of the external organization of ants will enable us to account for various relations that exist between them and the vegetable world.

The first relations between ants and vegetables have undoubtedly been those of the eaters and the eaten. There are in fact quite a number of species of ants that obtain their food from living vegetables. Of these the most celebrated, and justly so, are the harvester ants. Their habits were known in the most ancient times. "The ant," says Solomon (Prov. vi. 8), "provideth her meat in the summer and gathereth her food in the harvest." Aelian, an author of the third century of our era, not only notes their gathering of seeds, but describes the means employed by them to keep their grains from dampness and their way of preventing germination by boring through the germ outside of the seed. An Arabic book of the seventh century says, in speaking of ants: "They store up wheat for food and dry it in the sun. If they fear that the grain may germinate they take away its ball, cutting it in two fragments. If we reflect we will be convinced that the ant is an intelligent insect." Montaigne, who lived in the south of France and had traveled in Italy, was acquainted with the habits of the harvester ants, which he describes with great precision. "They spread," says he, "in the open air their grains and seeds to aerate, freshen and dry them, when they see that they are getting moist and smelling moldy, for fear that they may become corrupt and rotten. But the caution and foresight that they use in dealing with barley grains surpasses all that human prudence could imagine. For fear lest the grain sprout and lose its qualities and properties as a store of food, they gnaw the end of it where the germ is wont to appear."

These data, collected by the old authors, have, however, been controverted by recent authorities—Swammerdam, Buffon, Latreille, and, above all, P. Huber, the great observer of ants—and it was not until recently that Lespès and Moggridge clearly proved the industrious habits of the harvester ants.

The two principal species of harvester ants, *Aphænogaster* (*Atta*) *structor* and *A. barbara*, are rare in the north, quite common in central Europe, and abundant on the shores of the Mediterranean. The workers are remarkable for their differences in height and appearance. They

pass by insensible gradations to a form with an enormous head—a soldier. The description of their method of harvesting and preserving the grain we must borrow from Moggridge, that acute observer, who, at 32 years of age, being forced by phthisis to seek a climate less inclement than that of England, employed his latest strength in studying the ants of the neighborhood of Mentone.

Often upon uncultivated lands, there called the garrigues, are seen long trains of ants forming two continuous lines hurrying in opposite directions, one going away from the nest, the other toward it. The latter is laden with seed or capsules that the ants are carrying to their hill.

These files of foraging ants sometimes range to a considerable distance from the nest, seeking the seeds of grasses, peas, and other plants of the garrigues. They collect not only ripe seeds, but also understand how to detach from the plants green fruits. Thus we may see an ant climbing along the stem of a shepherds-purse (*Capsella bursa-pastoris*) and, choosing a green pod, disdaining the riper ones which let fall their seeds at the least touch, seize the peduncle of the capsule between its mandibles and, fixing its hind legs firmly as a pivot, twist the peduncle round and round until it is broken off. Then, laden with this burden, it descends, backing and turning as its load demands, down around the stem to reach its nest. In the same manner are gathered the capsules of chickweed (*Alsine media*) and the nutlets of little labiates such as *Calamintha*.

We may frequently see two ants combine for the purpose of breaking the peduncle of a capsule. While one is gnawing the peduncle the other will twist it off; but it seems that their mandibles are never strong enough to sever the peduncle by cutting alone. If grains of hempseed, millet, and oats are scattered in the neighborhood of the nest of the harvester ants, the insects hasten to carry them off, although those seeds are heavy burdens for them. But it often happens that they are deceived as to the quality of the articles they drag to their nest. Thus they may carry off objects not suitable for food: shells, bits of wood, fragments of leaves. If little procelain beads are scattered along the path of a harvesting train the ants will carry them toward their nest. They soon perceive their error, however, for after an hour of this fruitless labor they pass by their false treasures indifferent to them.

The seeds of a species of fumitory (*Fumaria capreolata*) are gathered by these harvesters. Now, beside this plant, there fall to the ground little galls inhabited by a small cynipid insect. Deceived by the resemblance between these galls and the seeds of the plant, the ants add them to their store, quite convinced that they are really seeds. What is the fate of the inhabitants of these galls? Is there not here to be solved an interesting problem involving mimicry of parasitic origin?

The situation of the nests of the *Atta barbara* is often indicated by the presence of a number of plants that grow around out of the refuse

accumulated by the ants. These are, in fact, to be considered as weeds of cultivation and strangers to the lavender and cistus covered banks of the garrigue, being plants sprung from seeds that the ants have brought and abandoned for some unknown cause. The plants thus transported belong to the following classes: Veronicas, fumitories, oats, a nettle (*Urtica membranacea*), bird chickweed, wild marigold (*Calendula arvensis*), snapdragon (*Antirrhinum majus*), a flax (*Linaria simplex*), watercress (*Cardamine hirsuta*), and goose foot.

Quite frequently these plants are found along the sides of minature gullies or crevices hollowed in the rock where their seeds have been washed by the rain and there germinate. Thus these interlopers have been drawn into competition with the primitive occupiers of the ground; they accompany the ants as the plants of our harvests accompany man. The ants serve indirectly in their dissemination, using, indeed, part of them for food, but yet assisting in the propagation of the species. As soon as the harvested seeds are brought near to the nest, some hundreds of workers are employed in separating them from the husks while others store them away in the depths of the ant hill. The refuse is dragged out of the nest, in the immediate vicinity of which are found heaps of débris formed of bits of straw, pods, and empty capsules.

The nest is simply hollowed out in the soil, but it seems that sometimes the ants know how to appropriate the work of certain beetles. Moggridge has, in fact, seen in one of the nests a cavity covered over by a spherical dome having walls of hardened earth closed at the bottom, there being a large circular opening at the top and a smaller one below. This appears to be a dome constructed by a beetle and used by the ants for storage purposes.

The floor of these grain cellars is well cemented. The rooms differ in size, being on an average as large as a good-sized watch. Each of these rooms contains about 5 grams of seed. A nest made up of from 80 to 100 rooms may contain a pound or more of seeds belonging to different plants. The majority of these are, however, from cultivated grasses, especially *Tragus racemosus*. These are evidently preferred because of their richness in alimentary principles.

Especially interesting are the means employed by the ants to prevent the germination of seeds. In examining 21 nests Moggridge found, among some thousands of seeds, but very few that had germinated; these were, nevertheless, attacked by the ants, who attempted to mutilate them in order to stop their germination. This arrest of germination caused by the intervention of the ants is unquestionable, but we have not yet discovered the exact means by which it is effected. In isolated or abandoned portions of the nest the seeds sprout and develop in the granaries, and if the ants are prevented from penetrating into one of these the seeds germinate there normally. It has been surmised that the ants could prevent germination by closing, with a gelatinous substance, the micropyle of the seed, through which it was

supposed that moisture penetrated to the interior of the grain. This hypothesis is, however, very doubtful. When the seed became sufficiently softened and ready to germinate, it was thought that the ants raised the micropylar seal and germination ensued. Since a more advanced growth, says Moggridge, would alter the nutritive qualities of their store, they hasten to gnaw off the tip of the radicle. Having effected this mutilation, they dry the seeds in the sun, then store them up anew. If by chance the seeds are moistened by rain, they are dried in the same way.

When the entire grain becomes soft and swollen, the ants devour its soft parts, which are charged with saccharine substances, of which they are very fond, and which serve to nourish their larvæ. The envelopes, in the form of bran, are rejected and carried outside to the rubbish heap.

The ants then know how to malt the seed of graminaceous plants, obtaining real malt as our brewers do. We need not discuss here whether they pursue this industry by instinct alone or whether they have acquired their skill by experience.

By using artificial light Moggridge was able to see how the ants gnaw the seed. One of them grasps firmly a portion of the farinaceous albumen while two or three others attack the seed with their mandibles, feed upon it, and finally yield their places to others. Thus we see that, unlike other ants that are nourished only by soft or liquid substances, the harvester ants attack solid substances, rejecting, however, those seeds which have never been softened, and attacking only those which have been dried after having begun to germinate. The hard envelope of hemp and similar seeds generally resists the attack of the ants, so that these insects wait until these envelopes are softened and burst by germination before they devour the oily contents. Although the buccal apparatus of ants is not suitable for the mastication of hard bodies, it answers perfectly well, when assisted by the hard, toothed mandible, for scraping or scratching small particles of farinaceous matter.

These ants have also carnivorous habits, and frequently pillage neighboring nests, but a consideration of this would take us too far from our topic. Harvester ants exist also in the Tropics. As early as the first of this century Sykes, and then Gordon, noted in India a harvester ant (*Pheidole providens*).

Certain ants are not only harvesters, they are also farmers. These American species of the genus *Pogonomyrmex* were studied throughout ten consecutive years by Dr. Lincecum and his daughter. The observations of those skillful observers have been published by Darwin. These large, brown ants bore a hole in the ground, about which they heap up earth to a height of from 3 to 6 inches, forming a low, circular mound, rising by a gentle declivity from its center to its outer border. If, however, the ant is building in low, flat, wet land, subject to inundation, it elevates the mound like a pointed cone to a height of 15 or 20 inches

more, and makes the entrance near the summit—a wise precaution that is also shown in the location of their nests, which are placed beyond danger from inundations.

The ants then destroy the herbage entirely around the mound, leveling the surface for 3 or 4 feet all about the nest. Within this sort of paved area no growth is tolerated except that of a species of grass (*Aristida stricta*). This plant is sown all about the nest, while other plants that start up in the vicinity are pitilessly gnawed. The grass, thus aided in its struggle for existence, gives an abundant harvest of small, white, flinty seeds quite similar to rice (ant rice). The plant is harvested a little before maturity, bundled up and carried into the nest. There the grain is separated from the husk, which is thrown out beyond the paved area. If the ants are surprised by an early setting in of the rainy season, their stores may be dampened. They then dry them in the sun, preserve the sound grains and store them anew.

Lincecum and Darwin thought there was no doubt but that this species of grass was planted designedly. McCook affirms, however, that it is not sown by the ants themselves, these insects merely preventing any other species of plant from growing around their nest. In autumn, after the harvest, the paved area is abandoned until the ensuing autumn, when the grass again springs up, appearing about the ant-hill in the same ring-like form, and is cared for by the ants in the same manner.

Mrs. Treat and McCook have also studied with the greatest care other species of *Pogonomyrmex* in Texas (*P. crudelis* and *P. occidentalis*) having similar habits. One of these collects the fruits of Compositæ.

We see already by these examples that the vegetarian ants may, notwithstanding the ravages they commit upon certain plants, yet aid to a certain extent in their dissemination. The loss of a considerable quantity of seeds is compensated for by the dissemination of those which, among the number collected, are necessarily overlooked by the ants. The insects, especially the agricultural ants, manifestly aid the plants of their choice in their struggle with the neighboring species whose physicochemical requirements are the same. Certain tropical plants make use of agricultural ants for the dissemination of their seeds; but, far from furnishing an aliment in return, they deceive their assistants by the resemblance of their seeds to those of plants they are in the habit of gathering.

Sometimes, also, the insect is led into error by the resemblance of seeds to the nymphal cocoons (*vulgo*, egg) of the ants. It is true that the ants find under the leaves of these plants a saccharine liquid of which they are very fond. An instance of this is our common *Melampyrum pratense*, that often grows in the middle of ant-hills. Its dehiscent capsule contains a single seed, smooth and white, bearing a most deceptive resemblance to the cocoons inclosing the nymphæ. The ants are deceived by this appearance, and bury these seeds with the

same care with which they conceal their cocoons. These facts have resulted from the researches of a Swedish botanist and a myrmecologist, Lundström and Adler. By reason of the long tigellus that carries the cotyledons, the *Melampyrum* is well adapted for germinating under stones. The assistance of the ants gives it easy command of this habitat which other plants are unable to dispute. The resemblance of the seed of the *Melampyrum* to the cocoon extends not only to form and color, but also to odor, the seed emitting an ant-like smell.

Throughout central South America there exists a leaf-cutting or visiting ant, also called the parasol ant, and known by the native as the saüba. It is the *Œcodoma cephalotes*. These ants construct in woods and plantations quite extensive dome shaped habitations. The domes form the roof of a nest that has passages extending far away into the ground and provided with numerous entrances, usually closed. These ants excavate long galleries, in which they accumulate masses, relatively enormous, of fragments of leaves that they have cut from trees. If an ant-hill has been inhabited by a single colony for some years, it may acquire very considerable dimensions. The activity of these ants is so great that they have been seen to pass and repass under a river a quarter of a mile wide. The earth from their digging is spread outside and forms a talus more than 40 feet in circumference and from 1 to 3 feet high.

The workers of this species are of three orders. The main body is formed by a small-sized order of workers with small heads. The large workers are of two kinds, one having a smooth, polished head, with ocelli upon the vertex; the other subterranean, having no ocelli, and, according to Bates, fulfilling, in the depths of the colony, some unknown function; whether they are soldiers is doubtful.

The small workers and the large workers with smooth, polished heads are a real scourge to cultivators, especially ravaging coffee and orange plantations. The small workers climb upon the trees, stand on the edge of a leaf and, by means of their toothed mandibles, cut from it a semicular piece, leaving only the large nervures. A quarter of an hour suffices for the operation, during which they use their hind feet as a center and point of support. When the section is nearly finished the ant seizes the piece between his mandibles and, by a sharp jerk, detaches it. He then descends, carrying his load upright. Sometimes he simplifies his task by dropping his booty to the foot of the tree, where other workers pick it up.

"When standing upon an eminence," says Ellendorf, "one can see columns of these tiny creatures in compact masses, with their green bannerets above their heads, looking like an enormous green serpent slowly gliding over the ground; and this picture, outlined upon a background of yellowish gray, is made still more striking by the fact that all their bannerets are agitated by slight undulatory motions."

These ants, by biting the grass close to the ground, make regular

roads which extend to their nests. These are trodden night and day by thousands of workers, and soon become smooth and bare, resembling the tracks of a cart wheel passing through the herbage. The severed grass is thrown out on the sides of the road.

The voracity of the *Œcodomas* is such that, in the countries they infest, it is almost impossible to naturalize certain trees, such as citron and orange trees. Lund states that, when on a voyage of exploration in Brazil, he was very much astonished to hear, during calm weather, a noise like rain, caused by leaves falling to the ground. He was standing under a laurel tree 12 feet high, having coriaceous leaves which were detached, although having their natural green color, thus having no resemblance to diseased leaves. He saw then that each petiole had upon it an ant that was trying to cut it off. Each leaf severed and thrown to the ground was seized by the *Œcodomas*, who immediately cut it up and carried the fragments to their nest. In less than an hour the tree was stripped and resembled a gigantic broom.

Did Lund meet with some other species of *Œcodoma* than the *Œcodoma cephalotes?* If not, the ants know how to modify their method of harvesting, sometimes cutting round pieces out of leaves still attached by their petioles, sometimes cutting the petiole directly through. The leaves are taken into the ant-hill in a condition neither too dry nor too moist. If they are too moist they are dried near the entrance, and, if rain continues, finally abandoned. If the weather is too dry the leaves are gathered only at night. By the opening or closing of certain galleries a suitable ventilation is also kept up. In order to facilitate this their hills are never located in the interior of forests, where the air does not circulate well, but on the edge of clearings.

Of what use can these harvested leaves be to the ants? Various hypotheses have been proposed on this subject. The most probable is that of Belt, who supposes that they are used to make a real compost on which small mushrooms grow, that serve the ants for food. If, indeed, we open an ant-hill we do not see there any leaves, but find in many communicating chambers a brown flocculent matter, in the midst of which are found ants much smaller than the leaf-cutting workers, together with larvæ and pupæ.

These little ants sometimes go out of the nest and follow the paths traversed by the workers; but they never carry anything, and are even themselves carried back again by the workers, seated upon the round pieces of leaves transported by the latter. There is apparently assigned to them the task of reducing to small fragments the leaves brought into the nest, and they work only in the depths of the colony.

It is not only leaves that are used by the ants to make their compost, but certain flowers belonging to plants the leaves of which they do not attack, and the inner white rind of oranges. Like the harvester ants of our own country, they sometimes carry in by mistake useless materials, but they soon discover this and drag them outside.

The *Œcodomas* are not the only ants that attempt the raising of mushrooms. A Brazilian species of *Atta* digs subterranean passages from its nest to the trees whose leaves it uses. These leaves, after being taken to the nest, are torn up and masticated till they have the appearance of a spongy gray mass. In this mass there develops the mycelium of an agaric (Möller), which forms small white masses "like cauliflower heads," the principal food of the ants.

We have now referred to three kinds of ants that live at the expense of plants, and whose depredations (if we disregard the benefit from the dissemination of seeds by the harvesters and others) are injurious to such plants. It is, therefore, not surprising to find in many vegetables special defensive provisions made against the ravages of ants. It should be noted that this provision is not always made against the ants alone, but in a general way against injurious apterous insects.

We have seen that certain harvesters attack the fruits of the Compositæ. We find, accordingly, that certain typical forms in this family surround their infloresence with a regular *chevaux de frise*. The example of the carline thistle shows this very clearly. The spinescent bracts of the involucre form, as in many thistles, an insurmountable hedge. The heads of the centaury have an involucre surrounded with little curved needles, the rest of the plant being smooth.

At certain times of the year a number of plants excrete from the surfaces of their leaves a sugary liquid. This is the case with the oak, whose leaves are in spring covered with "honey dew." This excretion is connected with the growth of the plant, and is caused, according to various authors, by retarded transpiration. Primitively it must have been a total loss to the vegetable economy, but little by little the plant has become enabled to utilize it. Various stinging hymenoptera, such as bees and ants, visit the leaves to gather this honey dew. There is no doubt but that phytophagous animals can not approach a plant thus covered with venomous insects without exposing themselves to numerous stings. Hence there is, in exchange for food, a real protection offered by the insects.

In the case of the oak the production of the honey dew is not localized, but extends over the whole surface of the leaf. But in the case of some other plants the production is localized at certain special points of the leaf which thus become true nectar glands, foliary or extrafloral nectaries, also called extranuptial nectaries, since they in no way contribute to the fertilization by insects. The production of the honey dew at these specialized places is less abundant, but is more constant than when it extends over the entire surface of the leaf. Hence the nectarivorous insects are more constantly upon the surface of the plant, and the protection against phytophagous creatures is more efficacious. These extrafloral nectaries are placed upon the aerial vegetative organs at points that vary in different plants. In the cherry tree, for example, some nectaries, in the form of small, red spherules, are found on the edges of the upper part of the petiole.

A study of the development of the leaf suffices to show that, morphologically, these represent aborted teeth of the limbus that have become adapted as nectaries. Between the serrate teeth that form the edge of the limbus of a number of leaves there are found in various plants small nectariferous glands (serration glands). In the wood-vetch the stipules, situate at the base of the compound pinnate leaves, serve as foliary nectaries.

It is quite natural to ask what can have been the cause of this localization of the production of honey dew at this particular point to the exclusion of others. The following explanation is reasonably satisfactory:

Nectarivorous insects, having acquired the habit of frequenting leaves covered throughout their entire surface with honey dew, continued to do so, even when the excretion had ceased; during periods, for example, when transpiration was not retarded. These leaves they subjected to suction, and if their buccal apparatus permitted it, as in the case of ants, to a continually repeated nibbling. In this respect these insects behaved like a young mammal who sucks the breast of his mother more energetically in proportion as she furnishes less lacteal secretion. Any irritation of a living tissue causes it to hypertrophy and proliferate. The localization of the irritation at certain special points causes the formation, at these points, of glands having a sugary secretion. Henceforward the nectarivorous insects localize their action upon these nectaries, and the remainder of the leaf may then adapt itself entirely to other functions, of which the most important is chlorophyllian absorption.

The formation of foliary nectaries may, in principle, be due to the intervention of phytophagous as well as of nectarivorous insects. The tendency which ants have to tear the leaves of young peach-tree buds is well known. It may be supposed that the bites of these insects upon the inferior portions of the leaf caused a progressive atrophy of that organ. These portions would be progressively adapted to a new function—that of nectaries. The plant, thus forced to adapt itself to the needs of the ants, would in this manner establish a modus vivendi between itself and those insects. In place of giving up portions of its foliary parenchyma, it would give them a sugary liquid. The ants would find every advantage in this substitution, the liquid being more easily assimilable and its collection by sucking being much more economical in time and labor than the mastication of the foliary parenchyma. In return the ants would protect the plant against the attacks of phytophagous creatures.

Along the edges of the leaves of the *Rosa Banksiæ* are found perifoliary nectaries that attract great numbers of a large black ant (*Camponotus pubescens*). The presence of these ants preserves the rose from the attacks of a hymenopterous insect (*Hylotoma rosæ*). We owe an interesting experiment upon this subject to Beccari. On a branch of *Rosa Banksiæ* attacked by ants he placed a branch of another rose bush

attacked by the larvæ of *Hylotoma*. Incommoded by the ants, these larvæ took refuge upon the youngest buds, unprovided as yet with nectaries, and consequently not visited by ants. It is to be remarked that the Banks rosebushes, which are rarely or never attacked by *Hylotomas*, are destitute of prickles. We may probably admit that there is a correlation between the presence on plants of thorns or prickles and that of leaf-eating insects. Is it not due to the protection given by ants and other sting-bearing hymenoptera that the Banks rosebushes attain the great age that some of them are known to do? We may cite as an instance one of these bushes planted in 1803 by Bopland in the garden of the marine hospital at Toulon, which has a stem a meter in diameter at the base and bears each year from fifty to sixty thousand flowers.

The leaves of peach, apricot, and cherry trees may, as there is reason to suppose, be derived from compound leaves. The nectaries which they carry on the petioles should then have the significance of aborted leaflets filled with sweet stores.

The extranuptial nectaries belong not only to phanerogams, they are also found in the vascular cryptogams. We find extranuptial nectaries at the base of sterile pinnules in *Pteris aquilina* and *Acrostichum scandens*. In *Acrostichum Horsfieldii* we find at the base of the sterile leaflets, and also frequently at the base of the fertile leaflets, small auricles that seem to be nectariferous.

Francis Darwin, who discovered the nectaries in the fronds of *Pteris aquilina*, does not believe in the defense afforded by the ants against phytophagous insects. In favor of this theory, however, is the fact that the secretion of nectar takes place only in young fronds whose tissue, yet tender, is an easy prey for the leaf eaters. It should also be noted that *Pteris aquilina* is a cosmopolitan plant. It may not attract insects in England, and yet do so in other regions. Besides, in France, an *Halictus* has been seen to visit the fronds of this fern. Ferns are not exempt from attacks by plant-eating insects. Beccari saw a *Cyrtomium plicatum*, cultivated in a court, with all its fronds covered by a green caterpillar. Not far from this fern were found stems of *Pteris aquilina* which had been reduced to small fragments by an insect. Beccari supposes that the same larva attacked simultaneously the fronds of the two ferns.

It is not only the normal organs of plants which may offer a sugary secretion prized by the ants. Certain galls may be considered as true foliary nectaries of parasitic origin. "The galls of *Andricus testaceipes* (*Aphilotrix Sieboldi*)," says Adler, "are greatly exposed to the attacks of various parasites of the genera *Torymus* and *Synergus*. It is interesting to observe how the gall has indirectly evolved a means of protection. Its red, sappy envelope secretes a sticky fluid eagerly sought after by ants, and that they may enjoy this nectar undisturbed, they build with sand and earth a perfect dome over the galls, and in this

way provide the inhabitants with the best protection against their enemies.

There are other honey-dew-galls that furnish ants with an excellent food. Such are the reddish-brown galls formed on the leaves of the *Quercus undulata* in the region of the Garden of the Gods, Colorado. These galls are frequented by the honey ant, *Myrmecocystus melliger*, whose habits, studied by McCook, have been recounted in most classical treatises. We need here only recall that these ants have two classes of workers—those charged with gathering nectar from the surfaces of the galls and sedentary honey-bearing workers whose abdomen is distended by the expansion of a bag filled with honey. The honey bearers do not form a class predestined to special functions by a peculiar physical organization. All neuter individuals may be transformed into honey bearers under the influence of special alimentation. There is no doubt but that the presence of ants upon the leaves of the gall-bearing oak may have for its indirect result the protection, first of the galls and then of their leaves, from the attacks of their various enemies. In this case the hymenoptera causing the galls render a service to the plant they attack by attracting to its vegetative organs a more or less permanent army of defenders.

The *Camponotus inflatus* and *Melophorus Bagoti* described by Lubbock are also honey ants. The *Crematogaster inflatus* of Malasia has its metathorax transformed into a bag filled with a sugary liquid and provided at the back with two orifices of discharge.

The production of nectar is not limited, as is well known, to the vegetative organs of plants. It is especially abundant in the floral organs where the nectaries attract pollenizing insects. The presence of the nectar attracts not only winged insects especially adapted to pollination but also aptera, ants in particular. In a number of cases the latter insects may rob a plant of its nectar without pollination being, in its turn, well assured. Hence we find a series of defensive or myrmecophobic arrangements having for their result the exclusion of ants from the floral organs.

It seems that, to low-growing flowers like certain Cruciferæ and Compositæ capable of pollination by ants, there is a certain advantage in the process being effected in a more assured manner by winged insects (Kerner). The chevaux de frise, to which we have called attention as surrounding the inflorescence in the carline thistle and the centaury, may be a defensive organ of the first rank. The wood scabish (*Knautia dipsacifolia*) has on its stem downward-pointing hairs through which the ants can not mount to the inflorescence. The teasels are protected by a sort of cup formed by the base of opposite leaves, a cup to which has been ascribed a very doubtful carnivorous function, from which the name "digestive trap," given it by Francis Darwin.

Vaucher showed some time ago that the Malvaceæ that have nectariferous flowers are provided with hairs, while those that do not produce

nectar have none. In other plants the leaves form about the stem a sloping surface in the form of a collar, or the vegetative organs may be covered with a waxy secretion that renders the leaves and stems, or perhaps both of these organs, shining, smooth, and slippery. The myrmecophobic function of these slippery surfaces has been shown by Delpino, although, as it seems to us, he has in a number of cases exaggerated the defensive rôle attributed by him to the glaucescence of the vegetative organs. In certain cases the glaucescence may be combined with another method of protection. Such is the case with the *Ricinus* or castor-oil plant, whose leaves are nectariferous and whose stem is glaucous (Delpino and Schimper).

If flowers with large corollas were visited by ants they could not usually be visited by winged insects, who are alone suited to effect pollination. A bee, for example, who might light upon a flower thus visited by ants might run the risk of having its proboscis, one of the most sensitive of organs, seized by the ants; hence the utility, for many insect-loving flowers, of protecting themselves against the visit of ants. In a considerable number of cases the protection is effected by foliary organs, as we have just indicated, but more frequently the plant protects itself. Pendent flowers having the peduncle inclined toward the ground offer by the very curvature of that organ an arrangement very likely to cause the fall of ants who may venture upon it. Besides, these plants are usually slippery. Good examples of this arrangement are observed in the snowdrop (*Galanthus nivalis*), the *Cyclamen*, the crown imperial (*Fritillaria imperialis*). These plants protect themselves as does the weaver bird, which places its nest upon the end of a flexible limb, where it will be out of the reach of serpents. If a flower is arranged horizontally or vertically it may protect itself by means of viscous hairs upon which the ants will be likely to stick. We may cite as an example of surfaces thus covered with granular, viscous hairs the peduncle of *Silene nutans*, of *Epimedium alpinum*, the flowers of the gooseberry, of the *Linnaea borealis*, of the *Plumbago Europea*, a plant considered by some authors as insectivorous (?).

Aquatic plants are protected by their very situation. Aquatic species of genera generally pubescent are smooth. Examples: *Viola palustris*, *Veronica anagallis*, *Veronica beccabunga*, *Ranunculus aquatilis*. In the *Polygonum amphibium*, studied by Kerner, the stigma is much larger than the corolla. If the ants should penetrate the interior of this corolla they would steal the nectar without pollenizing the plant; but if a winged insect should visit the flower there would be many chances of its brushing the stigma in its passage. The stamens are short and ripen before the pistil, so that any winged insect, however small, can effect pollination. But this *Polygonum*, as its specific name indicates, may also grow upon the land. As long as it remains in water it remains glabrous; as soon as it grows upon the land it becomes covered with glandular hairs.

If the flower has no stiff or viscous protecting hairs, if its peduncle is neither glaucous nor steep, it adopts various devices for the purpose of protecting its floral nectaries against ants—devices that affect various organs. In certain narcissuses the tube is so narrow that an ant can not enter. Only the proboscis of a winged insect can penetrate it. In the *Campanula* the flowers are widely open, but the stamens are so united as to form a sort of box, in which the nectar is found. Bees are very early risers, while ants do not go out until the dew is off. A flower which possesses no means of protection against ants has, therefore, an advantage if it opens early in the morning and closes its corolla before the ants arrive (Lubbock). Thus it is that the flowers of the *Tragopogon pratense* close early in the morning. Those of *Lampsana communis* and of *Crepis pulchra* open before 6 o'clock and close about 10 o'clock a. m.

The nectar-producing plants of England are generally pubescent. Lubbock has drawn up a list of 110 species that are nectariferous and smooth. In 60 of these the passage leading to the nectar is so narrow that the ant can not pass. Thirty are aquatic, 3 or 4 open only at night, 6 grow in the open ground but are very small, so that to them hairs would be of very doubtful utility.

In a number of cases the ants borrow the nectar from vegetables through the intermediation of animals. A true animal honey dew is secreted by plant lice (*Aphides*) or cochineal insects (*Coccidæ*). It is well known that these insects excrete from the posterior extremity of their digestive tube a saccharine liquid of which the ants are fond. Upon the leaves covered with aphides ants constantly circulate, and, tickling these creatures upon the abdomen with their antennæ gather the sugary drops that are then exuded. The adaptation of these aphides to the ants is so perfect that, according to Darwin, when one is tickled by a hair it will not give up its liquid, that result only following the excitation produced by the ant (?). However this may be, aphides and sometimes cochineal insects are truly purveyors to the ants. Linnæus called them *Vaccæ formicarum*, or ant-cows.

The habits of these pastoral ants are too well known for us to dwell upon them, but it is well to remember that there are, so to speak, two degrees of complexity in the relations of these insects. Many ants are content with collecting the nectar from the aphides in the open air, others construct covered ways and regular aerial stables to protect their "cows" from the attacks of their enemies and to "milk" them at their ease.

Sometimes, also, when the aphides frequent the subterranean parts of vegetables, they construct underground stables. In our country the aerial stables are temporary, made of loose earth and fragile, but Osten-Sacken has seen, near Washington, a branch of juniper carrying an aerial stable formed of agglomerated filaments having a resinous odor. He has even seen in Virginia an aerial stable, spherical but fragile, constructed upon an *Asclepias*. Trelease has also seen in North America aerial stables established by *Crematogasters* upon *Andromedas*.

The ants protect their charges against the attacks of their enemies; for example, against ichneumon flies that wish to deposit eggs in their bodies, and this with an almost maternal vigilance. They also protect them against wasps, greedy for the sugary secretion. If the ants have installed themselves upon a plant near the aphides it is very difficult for the wasps to drive them away. Those insects try to make the ants fall, and succeed in doing so, but soon other ants come to replace the fallen and the wasps are at length forced to give up the struggle.

The solicitude of the ants for the aphides is sometimes carried so far that they take them with them when they break up their nests. Such is the case with *Lasius fuliginens* and *brunneus* in whose hills is found an aphis (*Lachnus longirostris*) that frequents the bark of certain trees. When they change their domiciles the ants detach from the bark the rostrum of the aphis which, deprived of its protectors, would remain exposed to the attacks of its enemies.

In certain cases ants not only profit by colonies of aphides formed independently of their aid, but they also assist in founding others. The *Schizoneura venusta* is a winged aphis that lives at the base of the stem of certain grasses (*Setaria*). The ants tear the wings of the winged insects which they find on the ground, then dig a gallery so that they can reach a rootlet. The aphides having reached the nourishing plant, found there a colony that becomes, for the ants, a true subterranean dairy. To it roads are made in the ground to give passage to winged aphides charged with the dissemination of their species. In this case the aphis does not seem able, without the aid of the ant, to find the means of penetrating to the base of the plant that is to nourish it. The infesting of the plant depends directly upon the ants. A considerable number of aerial organs are thus peopled with aphides by the direct action of ants who transport the insects to noninfested plants. We will not dwell further upon the relations between aphides and ants, which interest us only because of the damage done to plants by the cooperation of those insects. The facts are, besides, detailed in most general treatises on entomology.

The relations of ants with the *Coccidæ* (scale insects) are essentially the same as those they have with the *Aphides* (plant lice). In our climate, where plant lice abound, they are, together with the *Coccidæ*, the only insects, or nearly so, that furnish ants with a true animal honey dew. But in South America, where aphides are much more rare, they appear to be replaced almost entirely by the larvæ of homopterous Hemiptera (*Cercopides*, and especially *Membracides*). The relations of ants with these insects have been studied by Beske, Swainson, and Lund. Besides the protection which the ants afford to the insects that excrete the honey dew they perhaps aid them in their moltings by relieving them of their old skin. Delpino has described the relations that occur in Italy between *Camponotus pubescens* and other ants and the larvæ of two Cicadellas (*Tettigometra virescens* and *Centrotus*

genistæ). In the United States the caterpillar of a species of *Lycæna* has upon its last abdominal segments two or three pairs of small projecting buttons provided with a central opening from which exudes, under the influence of the caresses of *Formica fusca*, a small drop of a special liquid.

As we have seen it is incontestable that the ants thus protect a number of insects injurious to vegetation against the attacks of their natural enemies, but in certain cases it seems probable that ants, by transporting these sucking insects from developing to older parts of the plant may considerably aid the vegetable to sustain the attacks of these parasites. For example, an aphis, by living on the young leaves of a bud, will frequently cause them to develop abnormally, while if it lived on the adult stem it would be much less prejudicial to the plant. Cases will hereafter be cited in which ants transport aphides and cochineals from one organ of the plant to another.

All these nectar-producing insects may be considered, generally, as walking nectaries. They attract ants much more powerfully than do the extrafloral nectaries. Traversing almost the entire surface of the plant, they determine the goings and comings of the ants, which thus indirectly protect the entire plant by their very presence instead of remaining massed at special points where nectaries are found. But it seems to us going too far to consider with Lundstrom that these walking animal nectaries are profitable to the plant. The quantity of nutritive materials they take from it, and the deformations they cause in a number of organs, are not compensated for by the protection, doubtful indeed in many cases, offered by the ants they attract.

The true plant-protecting ants are those which do not borrow (even indirectly by means of aphides) their aliment from the vegetable kingdom—those which are frankly carnivorous. Such ants are quite numerous in our climate, and their usefulness to agriculture and silviculture is incontestable. We find that *Formica pratensis* is very destructive to insects such as caterpillars and grasshoppers. A nest of this species will destroy as many as 28 insects per minute, or about 1,600 per hour. And such a colony works day and night throughout the entire season.

In the midst of the arid savannas of America the beneficent action of ants is shown by islets of verdure covering the hillocks raised by these insects. The protection which they give to plants prevents the attacks of leaf eaters.

We have not touched upon many well-known points in the above-mentioned biologic relations of ants. We prefer to concentrate our attention upon their direct relations with a number of plants that may be called *myrmecophilous*, since they afford shelter and often food to ants. The history of these lodging plants is generally little known, and they present a number of peculiarities which deserve to be studied in detail. The instinct of ants leads them to attempt to establish themselves in cavities where they may be sheltered. These cavities will be

more advantageous in proportion as they are convenient to the food which the insects seek. Therefore, if a nectariferous plant visited by ants presents in some of its organs a cavity suitable for their habitation, it will soon become a lodging for these insects.

Such is the case with various ferns. We have already mentioned the extra-nuptial nectaries found on the fronds of various indigenous and exotic ferns. On the lower face of the sterile fronds of *Polypodium nectariferum* nectaries are found in considerable numbers; but their origin is different from that of those observed in the before-mentioned types. They seem by their position to correspond to the petiolar nectaries of phanerogams of the types already cited. But in *P. nectariferum* they appear to be aborted sori formed at the points where the nervures divide, and therefore analogous to the floral nectaries of the phanerogams. The sterile frond of this polypod is quite different in shape from the fertile frond. The nectaries seem to attract the ants to it, and they find there assured shelter by reason of its special form.

The young shoots of palm trees are tender, usually sweet in flavor, and therefore exposed to be eaten by herbivorous animals. (It is well known that travelers who traverse the virgin forests of Malasia easily procure for themselves a succulent food by felling palm trees and cutting out their growing top shoots.) These plants are therefore usually protected by means of spines. Certain species for which this mode of defense is insufficient have recourse to ants for protection. Even those species that are armed with sharp needles have the younger parts comparatively unprotected, because the needles are not yet sufficiently hardened. The ants find a shelter upon these palm trees. Sometimes, as is the case with certain species of *Calamus*, the spathe that protects the inflorescence has a form suitable for harboring these insects. Sometimes, as in some species of *Dæmonorops*, the series of needles that arm the stem are curved toward each other two by two, thus forming, by their intercrossing on the surface of the stem, galleries, in which the ants establish themselves. In this case the lodging organ forms but a part of the wall of the cavity inhabited by the ants. It is, as might be said, the rough draft of a myrmecophilous feature. In the great majority of lodging plants the cavity is entirely formed by the organs of the plant.

In palm trees of the genus *Korthalsia* the lodging organ is of another character. The sheath of the leaves (ocrea) has an appendage that enlarges in the form of a boat, and thus shuts in, together with that part of the stem against which it is applied, a closed cavity. To get into this the ants make an opening in the median line or laterally, and in addition to this, which is used for entrance and exit, they make other small openings at the base of the ocrea for the purpose of ventilation. It is probable that the *Korthalsia* has nectaries in the petiolule of some of the segments of its leaves. It appears certain that the cavity of the ocrea is formed without any intervention on the part of the ants, but

the holes in it do not exist there naturally, and seem to be made by those insects. This, too, it would seem, is a rough draft of a myrmecophilous feature. (See Pl. XVII.)

Usually lodging plants offer to ants a well-closed cavity formed at the expense of one of their organs. Such is the case with *Acacia cornigera*, a small tree of Central America, about six or seven meters high, having at the base of each leaf two strong spines, representing modified stipules. It is generally allowed that it was Belt who first, in Nicaragua, studied the relations of this tree to ants. It had, however, already been mentioned and figured by earlier observers: Hernandez (1651), Hermann (1689), Commelin (1698), Plukinet (1691). The spines are strong and have been compared with some exactitude to bull's horns. They are hollow within, the cavities of the two contiguous spines intercommunicating. The leaves are bipinnate, and at the base of each pair on the median nervure there is found a crateriform gland which in young leaves secretes a honey-like liquid. These foliary nectaries attract a great number of ants, which are constantly running about from one gland to another.

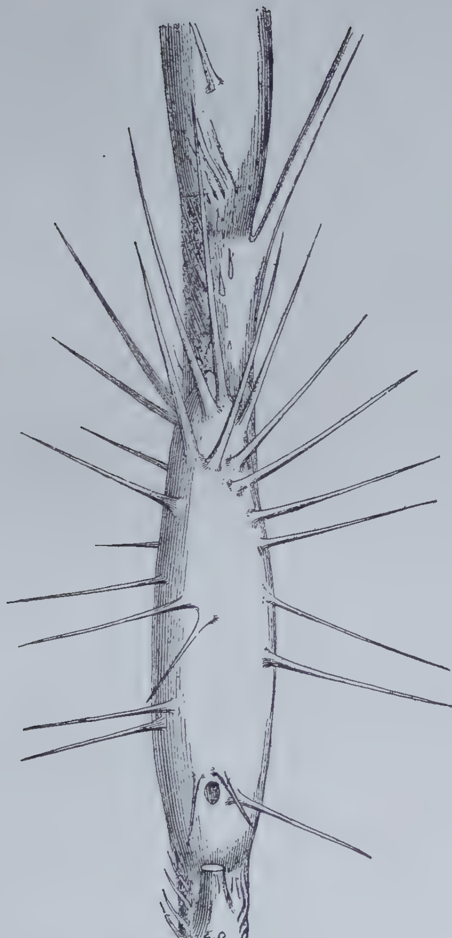
But this is not the only aliment offered to these insects. There are nectaries of another kind. At the extremity of each of the small divisions of a compound leaflet there is formed a little yellow fruit-like body, attached to the leaf at a single point. When the leaf first unfolds these little pears are not quite ripe, and the ants are continually employed going from one to the other examining them. When an ant finds one sufficiently advanced it bites the small point of attachment. Then, bending down the fruit-like body, it breaks it off and bears it away in triumph to the nest. The ants are therefore found continually upon the plant occupied in harvesting these glandules, which ripen successively. Since these organs are attractive to ants as dainties, Francis Darwin gave them the name of "food bodies." We may perhaps attribute the production of the "food bodies of the *Acacia cornigera* to the ants themselves. The ancestors of the plant must have possessed leaves that secreted at their borders a mucilaginous liquid in greater or less abundance. The ants, attracted by this liquid, began to nibble the secreting edge of these leaves, and thus produced an irritation resulting in a more abundant secretion of the liquid and an hypertrophy of the secreting parts. We have already spoken of the theory that accounts for the primary differentiation of the perifoliary nectaries by the irritation caused by the suction and bites of insects seeking mucilaginous or sugary liquids.

Belt has observed that two species of ants visit the spines of the *Acacia*. The most frequent visitor is the *Pseudomyrma bicolor*. The other is a species of *Crematogaster*. The two never inhabit at the same time the same tree, nor do they perforate the same spines at the same place, the former penetrating them near the apex, the latter about midway of their length.

Belt succeeded in cultivating this *Acacia*. His plants were covered with ants of a different species from those that lived on the wild tree. These ants frequented neither the foliary nectaries nor the spines, which they neglected to perforate. Deprived of their usual inhabitants, the spines differed from those of the usual plant, being but little developed, soft, and filled with a pulpy, sweetish substance. From this experiment it may be concluded that the presence of ants within the spines tends to increase the size and density of those organs, which can not reach their full development without the stimulus caused by such inhabitants.

It is to be supposed that the ancestors of the *Acacia cornigera* had no other defense against the attacks of herbivora than the protection afforded by their spines. The differentiation of foliary nectaries at first permitted them to utilize for their defense the constant visits during the day of certain bees whose venomous stings would put to flight the diurnal herbivora. But as the visits of these bees were only diurnal, the plant would remain exposed to the attacks of nocturnal herbivora. The adaptation of its spines for lodging the ants assured the *Acacia cornigera* of a constant defense. It may, however, be well to remark that the defensive arrangements are especially directed against leaf cutting ants rather than against other herbivorous creatures. The protection given to ants is so necessary to this *Acacia* that, according to Belt, its acclimation would be impossible in localities where the *Pseudomyrma* does not exist. The leaves of the plant, even when freed from the ants that inhabit them, are rejected by herbivorous animals, their repugnance to them being due, in great part, to the odor of ants exhaled by the leaves after they have been visited by the *Pseudomyrma*.

Beccari has mentioned a nutmeg tree (*Myristica myrmecophila*) whose internodes, provided with wing like prolongations of very curious form, are enlarged, hollow, and inhabited by ants, which reach the cavities by openings situated on the stem or on the peduncle of the male and female flowers. These openings have the form of narrow slits with raised edges. The cavities of the various internodes do not intercommunicate. We may suppose, by analogy with what is seen in other myrmecophilous types, that the perforations do not exist in the young internodes, and are the work of the ants that visit the plant in great numbers, as they likewise do other species of the same genus. The raised edges of the slits in the internodes apparently secrete a sugary liquid attractive to ants. These insects, besides the part they may play in driving off phytophagous creatures, may, perhaps, assist in the fertilization of the diœcious flowers of the nutmeg tree. The visit of insects is, in fact, indispensable to the fertilization of this plant, the male flowers having a convex receptacle and an ovoid calyx slightly tridentate at its upper part, and an andrœcium consisting of sixteen anthers, forming a cylindrical stipitate column entirely included within the tube of the calyx.



BIOLOGIC RELATIONS OF PLANTS AND ANTS.

Korthalsia echinometra, Becc —A lodging organ. (Beccari.)

The *Endospermum moluccanum* is a myrmecophilous euphorbiaceous plant known to the oldest authors who have treated of the flora of Malasia. It is the *Arbor regis* of Rumphius, "cujus truncus intus inhabitatur plerumque ea copia formicarum, ut vix aliquis arborum proprius, multo minus caudam altruncare audent." Its native name is caju sumut, that is, ant tree.

At the base of the leaves of this tree, where the limbus is inserted on the petiole, are found two nectariferous glandules that, there is every reason to suppose, are capable of attracting ants. It is not yet known whether the branches are hollow or not. Rumphius speaks, it is true, of openings upon the branches by which the ants pass in and out but it may be that his *Arbor regis* is rather *Hernandia ovigera*, a plant that is possibly myrmecophilous, or a related species of *Endospermum* of New Guinea (*Endospermum formicarum*), whose branches are hollow and provided with well-marked perforations.

One of the most interesting facts in the history of this tree is the following: It seems, according to the observations of Beccari, that it attains in its native forests such proportions as to justify the name *Arbor regis*, but when it is transported to tropical botanic gardens its height is considerably less. He considers the cause of this dimorphism to be the absence of ants from the cultivated plants, for he assumes that those insects, by the irritation in the internodes, stimulate growth. The ants, finding upon the *Endospermum* nectar and lodging, render it a signal service by causing indirectly its development. When the tree has attained, in its natal forest, "royal" dimensions its inflorescence overtops the other trees and the fertilization of the plant, which is effected by the wind, is greatly facilitated. Thus, in the most roundabout manner, the ants aid in pollination. This is a most curious example of an anemophilous plant becoming entomophilous, so as to utilize the visits of insects that indirectly aid fertilization.

The *Endospermum formicarum*, a species related to the preceding, has branches naturally and constantly enlarged and hollow, but we do not know if the perforations they present are produced by the agency of ants. Their position, which seems constant (in view of the few branches that are turned upward), gives rise to the supposition that this is the case, besides incomplete perforations are found involving only the bark and the outer fibers of the liber, and these must be the unfinished work of ants. There are also cicatrices which must correspond to the orifices commenced by ants and then closed up by the proliferation of the walls.

What stopped the ants in the work of perforation? The density of the internode, if they attack it at its base, a density that leads them to arrest their work and attack it higher up where the tissue is not so hard. These partially cut holes the plant closes up by cicatricial tissue.

At the summit of the petiole, near the bifurcation of the large nervures on the lower surface of the leaf, are found glandules that appear to serve as nectaries.

The ants are incapable of assisting in pollination, for the plant is diœcious and the pulverulent pollen seems to indicate that it is anemophilous. By causing the disappearance of the medullary tissue and thus rendering the branches lighter, the ants may facilitate the development of the tree, and consequently its elevation above the top of other trees, an arrangement especially favorable for the transportation of pollen by the wind.

The *Clerodendrum fistulosum* is a verbenaceous plant visited and inhabited by ants. Its straight stem, about a meter in height, has internodes that all appear enlarged. Each enlargement has at its summit, just below the insertion of the leaf of the internode above (one of the two opposite leaves of each internode having aborted), an orifice bounded by a projecting rim. The ants are attracted to the surface of the plant by little nectaries situated on the inferior surface of the leaves near the median nervure. It is not yet known if these internodes with their apical openings are absolutely constant features. Beccari supposes that the irritation produced by ants may cause a notable increase in the internodes and in the size of their cavity. The openings may have been in the first place the work of ants, though the cavities do not intercommunicate, for the ants that inhabit this *Clerodendron* belong to an eminently perforating genus (*Colobopsis*). It would appear, however, that at the present time these openings are produced without the intervention of ants, that a lesion has become hereditary. The services rendered by ants to the *Clerodendron* are, first, a protection against herbivora. Delpino saw a plant of this genus (*C. fragans*) defended by armies of ants as soon as anyone attempted to gather its flowers. Then these myrmecophilous features may assist the *C. fistulosum* in its struggle for existence with neighboring species. The irritation produced by the ants may perhaps cause a notable increase in the internodes and their more effective lignification, the subherbaceous plant being thus enabled to struggle with more advantage against rival species in the midst of tropical vegetation largely of a ligneous character. If this is the case we may suppose that primitively individuals inhabited by ants survived in preference to those which were not so inhabited, and natural selection consequently fixed these myrmecophilous features. The swelling of the internodes and the perforations, at first accidental characters, became normal.

Everyone has heard of the curious *Nepenthes*, commonly reputed to be carnivorous plants. The *Nepenthes bicalcarata* is one of the most interesting species of the genus and is to-day cultivated in the hothouses of Europe. Its climbing stems ascend trees to a height of from 10 to 15 meters. Its leaves are terminated by ascidia or pitchers, having the well-known form peculiar to the genus, which has caused the plant to be regarded as one of the most carnivorous of vegetables. These pitchers are so markedly dimorphic that they might be supposed to belong to two different species. The leaves of the upper part of the

BIOLOGIC RELATIONS OF PLANTS AND ANTS.

Clerodendron fistulosum, Becc.—Stem and inflorescence. (Beccari.)

stem have a peduncle that turns upon itself with a spiral coil opposite the most swollen portion of the pitcher. Its cavity does not extend beyond the enlarged portion of the peduncle. The leaves situated at other levels of the stem have a straight peduncle joining the pitcher at right angles and enlarged at the junction. The enlargement is hollow and also has an opening where it touches the pitcher. In neither of these forms is there any communication between the cavity of the pitcher and that of the peduncle. The axis of the male inflorescence is traversed by a median canal communicating with the exterior by several openings, which, like those made in the peduncle, have every appearance of being the work of ants that inhabit the cavities of those organs. We are unfortunately not informed whether the peduncles of hothouse plants have the enlargements so characteristic of the wild form, or whether the perforations are wanting if ants are absent. It is to be supposed, reasoning from analogy, that the enlargements are constant, but the perforations are the work of ants which have removed from the cavities of the peduncle and the inflorescence a spongy tissue like that belonging to the *Acacia cornigera*. As to the first cause of the formation of these peduncular enlargements we may perhaps find it in the bites of the ants. This differentiation, traumatic in its origin, might become hereditary in the course of time.

If it be true that the *Nepenthes* are really carnivorous plants (which in the present state of our knowledge seems doubtful), the species may utilize in two ways the hospitality it proffers to ants. Those insects may defend it against plant eaters, and if while running about the surface of their host they chance to fall into the traps formed by the pitchers, the plant may use their carcasses for food. The ants would thus serve the plant both for defense and for prey. (Pl. XIX.)

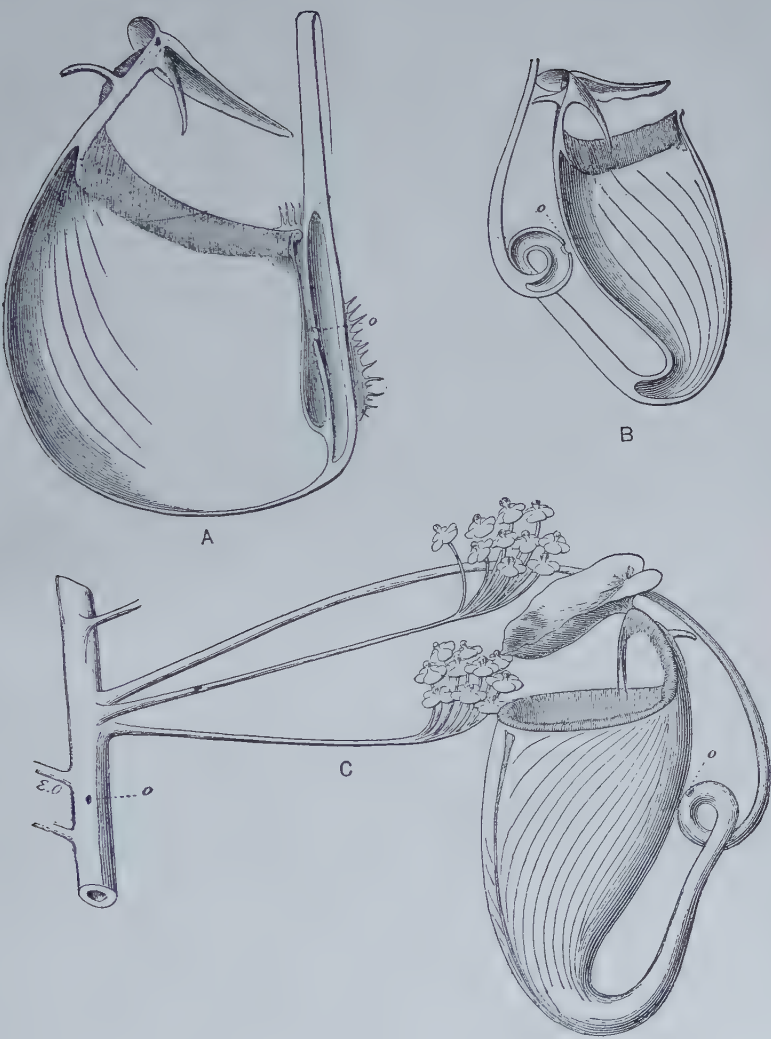
The species of *Kibara* (*K. formicarum* and *K. hospitans*), a genus of the family Monimiaceæ, have perforated internodes, either solid or hollow, that are visited by ants (*Hypoclinea scrutator*). Within the hollow internodes are found numerous individuals of a species of cochineal (*Myzolecanium Kibaræ*) that has a very well developed rostrum. Although it is not possible to determine in the dried specimen the presence of an excretory apparatus, there is reason to suppose that these insects give out a sugary liquid sought for by the ants. Biological relations ought then to exist between these inhabitants of the *Kibaras*, and it is not probable that the cochineals enter by themselves the cavities of the internodes. They have doubtless been conveyed there when young by the ants and there finish their development, the pregnant females attaining such dimensions that it is impossible for them to leave the cavity by the orifice of entrance. The ants have, then, undertaken the raising of cochineals within the internodal cavities of the *Kibara*. The orifices of entrance to these stables seem certainly to be their work. In fact, at the base of the internode there are found small, superficial perforations, apparently the result of

abortive attempts at penetration made by the ants, the resistance of the tissues there having caused them to abandon the effort, which, however, easily succeeds at the upper part of the internode, where, from an early age, the medullary tissue is less dense and the peripheral tissues less resistant. Perhaps the irritation produced by the ants may cause an increase in the diameter of the internodes and of their cavity.

The ants doubtless render to the *Kibaras* services of various kinds; first, protection against plant eaters; then transportation of the cochineals to a location where they will be less injurious than upon the young and undeveloped parts; finally, fertilization of the flowers.

The *Kibaras* are, in fact, monœcious, and their floral structure is such that their fertilization seems impossible without the intervention of insects. In exchange for these services they offer these ants a cavity for lodgment, and very likely an aliment indirectly furnished by the cochineals.

The *Cecropia adenopus* is a plant of Brazil, belonging to the Araliaceæ, that in its native country bears the name of *Amboiba* or *Imbauba*. As long ago as 1648 Marcgrave said of it "Totus intus cavus a radice ad summum usque et cavitas illa per interstitia semi digiti ubique distincta et transversali membrana, in cujus medio foramen rotundum magnitudine pisi. In hac cavitate reperiuntur semper formicæ rubræ ipsa coloris et hepatici." The medullary tissue is narrow at the base of the trunk, enlarging above, and is interrupted at each node by a ligneous disk. Two consecutive disks thus bound a closed cavity corresponding to an internode. In these cells the ants pursue the culture of cochineals. This is a myrmecophilous feature similar to that which Beccari pointed out in *Kibara formicarum* and *hospitans*. Belt and Fritz Müller have studied the relations of this plant to ants. According to the latter author there is a small cavity in the upper part of each internode, where the wall of the internodal chamber is thinner. At this point a pregnant female ant makes a hole in order to penetrate the chamber. These perforations can be plainly seen in herbarium specimens. Their relative position is perfectly regular, and they can by no means be considered as accidental. The ants once installed in the chambers, perforate the nodal disks and may thus circulate, under shelter, throughout the entire length of the trunk (Belt). Three species of ants frequent the *Cecropia*, but if either of these species is present the others are not found upon the tree. Fritz Müller thinks, on the contrary, that perforation of the disks does not take place. These two opinions, apparently contradictory, may perhaps be easily explained. Possibly the various species of ants that frequent the *Cecropia* may not have identical habits. Some may leave the disks intact, others may perforate them. Each of these observers may have been dealing with a different species of insect. Perhaps, also, they did not observe the same species of *Cecropia*. The *Cecropia adenopus* may not be the only one that presents a hollow stem separated into chambers by nodal



BIOLOGIC RELATIONS OF PLANTS AND ANTS.

Nepenthes bicalcarata, Hook.—Ascidia and inflorescences. (Beccari.)

disks. The same features are found in most of the species of that genus, which are, without doubt, myrmecophilous.

The utility of the ants for the *Cecropia* they inhabit may consist entirely in the protection they afford. This protection would be not only against plant-eating animals, but also against cochineals. We may suppose that the latter are transported from the surface of young buds, where they would be injurious to the normal development of the leaves, to the cavities of the stem, where their injurious action would be less. The ants here act like our gardeners who free hothouse plants from infesting scale insects. But the honey dew of cochineals being endowed with nutritive properties, the ants do not destroy them, but merely transport them to a part of the plant where their life is more compatible with the normal evolution of the vegetable. There would thus be established a consortium of three members—between the plant on one hand and the cochineals and the ants on the other.

Upon the *Cordia Gerascanthos* we find enlargements of the branches that are terminated by axes of inflorescence. Into these enlargements the ants make openings, using, perhaps, the place where some little bud is implanted. The cavity of the enlargment at first contains a flocculent tissue that the ants remove so that they may arrange within the cavity disks like a sort of pasteboard. In this domicile the ants pursue the raising of cochineals. It should be noted that these enlargements do not appear to be constant in the species.

In another species of the same genus, *Cordia nodosa*, the internodes, especially those bearing the inflorescence, are enlarged and hollowed near the insertion of the opposite leaves. The cavity communicates with the outside by an orifice situated, not laterally, as in the preceding species, but at its top. Both cavity and opening seem to be natural and not affected by the agency of ants. In cavities not yet visited by ants the internal surface is invested with stiff scattered ridges, some of which hang over the opening. In this species the lodging organ is formed hereditarily all ready for occupancy by the ants without any preliminary labor on their part. The myrmecophilous features merely outlined in the first species of *Cordia* would thus attain their perfection in the second and their origin be purely hereditary. This is an excellent example of the fixation of a character primitively accidental, and, so to speak, teratological. If the ants vary the place of penetrating the lodging cavity, the opening they make will not tend to become hereditary—that is to say, to reproduce itself independently of their action. This is the case, for example, in *Acacia cornigera* and the *Endospermums*. But if the ants always make their opening at the same point, the lesion tends to become a part of the morphologic plan of the vegetable. The point of lesion in the ancestor becomes a point of less resistance in the descendant—that is to say, a point where the ants can make an opening with the greatest facility, as the wall of the lodging organ would there be thin and easily perforable. In those

types in which myrmecophilous evolution is most advanced the perforation will become hereditary and the cavity of the lodging organ communicate with the exterior independently of any action on the part of the ants (*Clerodendon fistulosum*).

In all the cases we have reviewed the ants do not seem to have established themselves in organs whose differentiation relates to the habitat of the host plant. A considerable number of host plants are epiphytes, subject to peculiar physical conditions. They have to especially struggle against drought, and a number of them possess in their organs true reservoirs of water. The best known of these myrmecophilous epiphytic plants are the *Myrmecodias* and the *Hydnophytums*. We will dwell especially on the former because of the interesting observations that have been made upon them.

The *Myrmecodias* and *Hydnophytums* are epiphytes belonging to the Rubiaceæ and attach themselves by means of adventitious roots to the branches of trees, often at a considerable height. These plants are almost wholly formed of large tubercles, globular or cylindric in form, surmounted by one or more leafy stems. These tubercles, which may be either smooth or prickly, enlarge so as to attain several decimeters in diameter. (Pl. XX.) Instead of forming a solid mass their internal tissue is traversed by a system of intercommunicating cavities and passages that open externally by one or more quite large openings and numerous narrow orifices scattered over the entire surface of the tubercle.

All those who have collected these strange plants in their natural habitat have found their tubercles inhabited by ants scattered in great numbers throughout the galleries and passages. It was Rumphius, the old explorer of the Malay Archipelago, who first called attention to this. According to him the ants not only inhabit the tubercles, but they produce the entire vegetable. "This is," he says, "a strange creation of nature springing up without father or mother, * * * for it is known that these plants spring from the substance of the nests of ants where there can never have been any seeds, and yet each colony forms a separate plant." Rumphius then distinguishes two kinds of *Nidus germinans*, according to the species of ants found therein: *Nidus germinans formicarum rubrarum*—that is, a *Myrmecodia*, and *Nidus germinans formicarum nigrarum*—that is, a *Hydnophytum*.

It was Beccari, the eminent explorer of Malasia, who made the first accurate observations upon the biology of these curious Rubiaceæ and their relations to ants. These observations led him to suppose that the presence of the insects was indespensable to the plant. He thought he had ascertained that at the time of germination the tigellus merely thickens a little at the base and takes on a conical form with the cotyledons opening at the summit (Fig. 2, Nos. 1–5, Pl. XX), thus remaining until a species of ant hollows a little cavity in its side at the most swollen part of the tigellus. If the tigellus is not attacked by the ant

the plant dies; in the contrary case the wound made by the insect causes a considerable development of cellular tissue, the tubercle enlarges, the stem develops. (Fig. 2, Nos. 6, 7, Pl. XX.) Soon the ants find a sufficient space in which to found a colony, and they excavate within the tubercles galleries in all directions. If this view is correct, these plants could not live nor develop without ants. These insects must contribute to the formation of the organ that is to be the water reservoir of the plant. But on the other hand the ants could not live and reproduce their kind if they had not at their disposal plants in which they could construct such a living home.

According to Beccari the tubercles of the *Myrmecodias* and *Hydnophytums* are products primitively foreign to the plant. They are developed in the same way that galls or cecidia are—that is to say, they are produced upon vegetable organs in consequence of irritation caused by various insects. There is a striking analogy of form, and, indeed, of internal structure, between these tubercles and a certain gall formed by a curculio of the genus *Centorynchus* on the root of the garden cabbage. The larva of this insect feeds exclusively on the cortical portion of the root. As fast as this food is consumed a new generating layer proliferates and replaces the destroyed tissue. The life of the insect is perfectly compatible with that of the plant. It injures no essential organ, and the losses to which the plant is subjected are compensated for by the hypertrophy of the tissues under the irritation caused by the insect.

This analogy between the tubercles of the *Myrmecodia* and the gall formed on the cabbage by the *Centorynchus* may suggest the hypothesis that these tubercles are organs whose development must have been caused by a parasitic lesion made, perhaps, by ants, which are known to attack for food vegetable tubercles—potatoes, for example—as we have ourselves seen. This lesion might be at first merely compatible with the life of the plant, then useful to it, by the adaptation of the injured and hypertrophied organ to an organ for the storage of water. Fixed by selection, this character, at first accidental, would finally become hereditary. In order to know what credit to give this hypothesis it is necessary to study in detail the existing relations between the ants and the *Myrmecodias*. There is no doubt that ants, even in our own countries, sometimes establish themselves within certain galls that have been abandoned by the insect that produced them. Such is the case with a gall formed upon the *Cynara cardunculus* by a curculionid larva (*Larinus?*).

Is there between the *Myrmecodias* and the *Hydnophytums* on the one side, and the ants on the other, a reciprocal exchange of services, mutualism, symbiosis in the strict sense of the word, or, indeed, can not those plants do without the ants; are not the insects merely commensal? The interesting researches of Treub upon a Javanese species of *Myrmecodia* allow us to partially answer these questions.

We must first study the structure of the young plant, then the

changes that occur in its tissues up to the time when the young tubercle has an external opening giving access to an internal gallery.

The first cavity or gallery in the young tubercle is not hollowed out by the ants. It does not start from a lesion of the peripheral tissue, due to insects, but is the result of an internal differentiation. A transverse section of a young tubercle shows a parenchymatous homogeneous mass, inclosing in its center a libero-ligneous fascicle, and limited at the periphery by an epidermic layer. The growth and subdivision of the parenchymatous cells produces a thickening of the tubercle, at whose periphery is formed a generating layer of cork. In proportion as the tubercle grows, it forms, at the expense of some of the parenchymatous cells, new libero-ligneous fascicles, arranged parallel to the surface of the tubercle, and soon becoming connected by transverse anastomoses, not only with each other but with the fascicles of the stem and of the root. The formation of these peripheral fascicles indicates the beginning of the first gallery. A generating zone, parallel to the surface of the tubercle and situated deeply within its mass, begins to differentiate. All the parenchymatous material that it incloses in its interior then begins to dry up. This dessication brings about a rupture of this material, and there is thus formed the beginning of a central cavity circumscribed by a layer of cork, the result of a differentiation of the generating sheet. This cavity, cylindrical in its general form, extends in two directions. Above, it ends in a vault near the insertion of the stem, properly so called; below, it approaches the periphery. At last it constitutes a gallery nearly in the axis of the plant, lined with a layer of cork and inclosing a flocculent matter, the remains of the primitive parenchymatous tissue. The gallery is separated from the exterior by a thin peripheral layer of cork which soon tears and permits communication from without.

The essential point is that the generating layer results from an internal differentiation, and not as a consequence of the sting of an insect. This generating layer, which toward the interior of the tubercle produces cork, forms externally parenchyma, which contributes to the increase in thickness of the tubercle. In proportion as the tubercle thickens the number of galleries that traverse it increases. The new galleries are formed by a process identical with that which gave rise to the first gallery.

Although the first gallery is spontaneously formed in the young tubercle, it is possible that the hypocotylous axis did not thicken enough to produce it without the stimulus of an ant, by a bite perhaps imperceptible. But the lower part of that axis commences to thicken as early as the first stage of germination (fig. 2, Pl. XX). Why should not that spontaneous thickening continue? We may add that the young tubercle is provided with chlorophyll, and can assimilate even at the time when the cotyledons are yet inclosed in their seminal envelope. According, then, to these observations, the sting or bite of an ant

1. *Myrmecodia echinata*, Jack.—Longitudinal section of tubercle. (Treub.)

2. *Myrmecodia echinata*, Jack.—Successive stages of germination. (Treub.)

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apparently is not necessary to induce the primary thickening of the tubercle nor the formation of the internal cavities. An important observation of Beccari is opposed, however, to these conclusions. He noticed that only those plantlets increased in volume that were provided with a small cavity at the base of the enlargement. Those that did not have this rapidly perished. He supposes that the cavity in question is hollowed out by ants. The irritation produced by these insects would then be absolutely indispensable for the proper development of the plantlet.

A demonstrative experiment still remains to be made: to sprout the seed and obtain hollow tubercles without the intervention of ants. This has not been done up to this time, for in tropical countries the abundance of ants is such that under the conditions proper for the development of the plantlets we can never be sure that no ant has approached the germinating seed. But there is a very direct and very conclusive experiment due to Treub, which is as follows: Transported from their normal habitat into tropical botanical gardens, the tubercles are abandoned by the red ants that inhabit them in the forest. Very often these are replaced by little black ants. In spite of this change of inhabitants the plant continues to flourish, its tubercle enlarges, new galleries are formed in it, new leaves are produced, and fructification ensues. It appears, then, that if the presence of ants is necessary to the plant, it is not a particular species of ant that is required. But this is not all. The majority of the tubercles commence to rot at the time of their transportation, and this rotting causes the flight of the ants. At the end of a certain time the tubercles again become swollen and healthy, again commence to grow, to thicken, and to form new galleries, and all this in the absence of ants.

The ants, then, are not at all indispensable for the renewal of development in the adult plant. From the experiments of Treub we can, indeed, deduce but one fact: that in the adult state certain *Myrmecodias* can dispense with the presence of ants. We do not yet know whether this is the case with young plants, whether in the absence of ants a *Myrmecodia* can pass through all stages of development from the germ up to the adult. In certain species of this genus the myrmecophilism may be facultative, in others obligative.

Beccari justly remarks that the tissue which lines the galleries has all the characters of a young tissue likely to actively proliferate and to react energetically to any irritation that might be caused by the presence of ants. Its reaction to irritation might take the form of a proliferation of its constituent elements, as occurs in the tissues of a newly formed leaf when it is subjected to the irritation caused by a gall-insect. The irritation produced by ants upon an adult tissue would not cause the proliferation of its elements, though it might easily do this upon young tissue.

Though direct proofs are wanting, we are yet authorized in some

degree to continue to admit with Beccari that it is the presence of the ants, dwellers upon the *Myrmecodias* (*Iridomyrmex cordata* var. *myrmecodiæ*), that leads to the formation of the first gallery in the tubercle. These ants must have perforated the epidermis and penetrated into the central cavity of the hypocotyl, the irritation they produced there determining the hypertrophy of the latter and transforming it into a tubercle. As the tubercle acts as a reservoir of water, the plantlet that is deprived of it is necessarily condemned to perish as soon as the drought affects it. The development of the leaves, which are organs of transpiration, hence occasioning a loss of water, does not occur until after the development of the tubercle, the water storer. Now the ants invade the hypocotolous axis when it is surmounted merely by the two cotyledons.

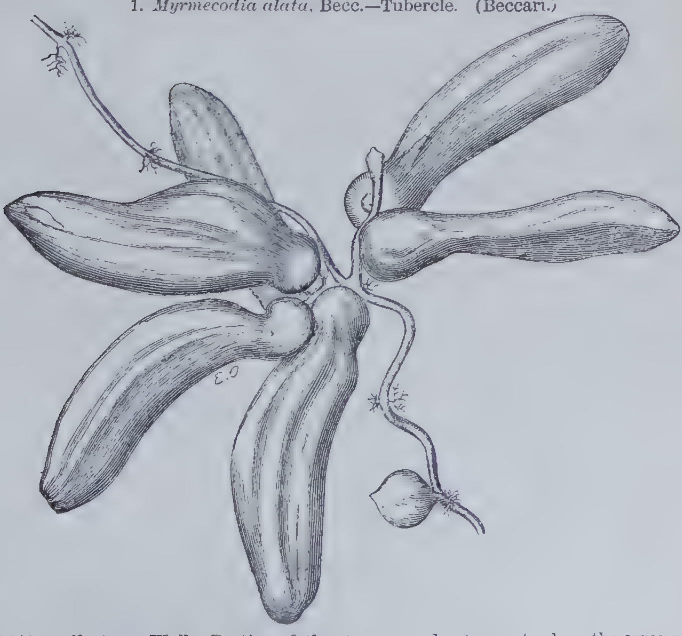
Let us now examine another point. Are the ants capable of making perforations and of hollowing out the galleries in the tubercles?

The examination of species of *Myrmecodia* is especially instructive in regard to this matter. *M. bullosa* shows at the base of its tubercle a few openings (one to four) of quite narrow galleries that end, at the periphery of the organ, in cavities somewhat similar to the cells of a honeycomb. In these recesses there are very numerous colonies of ants, and ventilation is difficult. To avoid the danger of asphyxiation the ants perforate the outer walls of the galleries with minute holes that dot the surface. The surface of the tubercle of *M. alata* has small gibbosities corresponding to the blind ends of certain galleries (fig. 6). Around these eminences are also seen small, dot-like ventilating holes that may, by becoming confluent, cause the detachment of the cover closing in the gallery, and thus make a new entrance to the passage.

It would be ascribing a very high degree of intelligence to the ants to admit that they could corrode, from the outside, a circular series of points exactly corresponding to the bottom of the gallery. They undoubtedly form their ventilators by working from within outward upon the inner wall of the gallery. The corrosive liquor (probably saliva) secreted by the ants not only destroys the cells with which it comes in contact, but also causes the formation of a cicatricial tissue that borders the perforating opening. There also seems to be no doubt but that the ants continually increase the diameter of the galleries when the dimensions of these passages become too narrow for their needs. In fact, once stripped of the dead flocculent tissue that at first fills them, the galleries have a constant tendency to fill up by reason of the internal proliferation of the layer of growing tissue that lines them. The ants must remove this, as it constantly tends to invade the gallery and decrease its caliber.

It is evident that the presence of galleries within the tubercle does not in any way assist the function of that body as a reservoir of water. Still, it may be admitted that the galleries, as asylums for ants, serve

1. *Myrmecodia alata*, Becc.—Tubercle. (Beccari.)



2. *Dischidia rafflesiana*, Wall.—Portion of the stem spread out so as to show the arrangement of the urns. The adventitious roots near the urns have been purposely omitted. (Treub.)

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the plant indirectly in its struggle against drought. The irritation produced by the insects causes an hypertrophy of the tubercle and consequent increase in the size of the reservoir. If the galleries were primarily the work of ants, they must have been, on general principles, unfavorable to the plant, which has, however, by progressive adaptation, finally utilized them.

On reflection we are led to believe that the labyrinth within the tubercle must be a feature very useful to the plant. It permits an active circulation of atmospheric air within the tubercle, and the presence of oxygen may be necessary for the elaboration of certain nutritive principles within its tissue. But the utility of this feature seems to be of another kind. The suggestion we are about to offer has not been proposed by any of those who have occupied themselves with the study of these plants, yet we think it merits attention. The corky layer that invests the entire surface of the tubercle is an obstacle to gaseous interchange between that body and the exterior. Such interchange can only take place by means of the air that circulates in the galleries. There, too, it can only be effected by the lenticels, since the internal surface is also lined with a corky layer, except where these lenticels are found. Now, sudden changes in the hygrometric state of the surrounding air will be but slowly transmitted to the air of the galleries, and it is this hygrometric state that regulates the interchange of water vapor between the tubercle and its environment. The presence of the labyrinth of galleries would then permit the plant to adapt itself more readily to the hygrometric changes in the circumambient air, which changes must be sudden, owing to the epiphytic situation of the plant. In case of drought the plant finds in its tubercle a reserve of water, its fleshy leaves transpire but little, and finally the air of the galleries is nearer the point of saturation than is the surrounding air. Hence the transpiration of water by the lenticels is less than it would be if they were exposed to the dryness of the surrounding air.

Some of the walls of the galleries of the *Myrmecodia* are smooth, others (Pl. XX) studded with little prominences that might *a priori* be supposed to be glands for absorbing nutritive principles derived from the decomposition either of the carcasses of ants (a rare case, since the dead are usually dragged out of the nest), or of detritus occasioned by the work of those insects. Treub has made a careful study of these prominences and has shown that they are internal lenticels, differing but little from the ordinary external lenticels. It is well known that the function of the cellular masses forming the lenticels is to supply atmospheric air to the tissue of the plant. The lenticels of *Myrmecodia* differ from those of other plants by absence of the central aeriferous passages; but all about them the files of peripheral cells are filled with air, and this may compensate for the lack of passages between the central files. It is also possible that certain protoplasmic-bodied cells that surround the lenticels like a collar serve to elaborate and

transform nutritive principles in presence of the abundant free oxygen brought to them by the active circulation of air in the cavities of the tubercle.

Beccari, on the contrary, is inclined to consider the eminences that stud the galleries not as lenticels, but as organs of absorption analogous to those of moisture-loving plants (*Corallorhiza*, *Epipogium*, *Triulis*, etc.). It may be remarked that certain terrestrial parasites, such as the Balanophoreæ, possess, on their parts that come in contact with the soil, organs quite similar in appearance to the lenticels. It is with these apparently absorbent organs that Beccari correlates the internal eminences of the galleries. If this supposition is correct, the interior of the galleries bristles with true internal roots.

The figure given by Treub of these lenticels in course of formation reminds one of the formation of a callus upon the cut surface of a cutting. The conditions that determine the formation of this callus—darkness, moisture, heat, a nutritive environment—are realized in the galleries of the *Myrmecodia*. The functions of the callus of a cutting are perhaps absorbent. A cutting upon which a callus is formed is sure to "take," which is about the same thing as saying that the absorption of nutritive substances is assured. Certain of these supposed lenticels may be transformed into real adventitious roots, which seems to confirm the theory that their function is absorbent. In spite of the great quantity of nutritive matters they contain, the lenticels are never gnawed by ants. There is therefore no reason to consider them as food bodies. These lenticels can not in any case act the part of organs that secrete digestive ferments. Their absorbent power for nutritive substances brought from without is still doubtful.

One point remains established. The ants penetrate the tubercle of the *Myrmecodia* and live there because they find an assured shelter. But it would be going too far to say that they render no service to the plant on which they lodge. The circulation of air in the galleries of the tubercle is probably indispensable, and the presence of a flocculent tissue there is well calculated to impede circulation. Perhaps the ants free the young galleries from the flocculent mass of dried cells. This would be a case of mutualism quite analogous to that of certain acarids known to install themselves upon the fur of mammals and the down of birds for the purpose of removing epidermic débris that incumbers their hairs and feathers. The ants, like the acarids, act the part of scavengers.

There seems to be no doubt but that ants may form an army of defenders useful to the plant in case it is attacked by plant-eating animals. It is an established fact that if a tubercle inhabited by the ants is struck, even slightly, thousands are seen to emerge and swarm on the surface, reentering their domicile as soon as the danger is past. But this has not been demonstrated upon plants in their natural wilds.

The part played by ants in fertilization is doubtful. The *Myrmecodias*

appear to be normally self-fertilizing. Since their flowers have no nectaries for attracting insects suitable for effecting fertilization, we can not say that the presence of ants on the surface of the plant tends to drive away apterous insects that might appropriate the nectar without profit to the plant.

Perhaps the ants might in certain cases assist in transporting the seeds of the plant, which are covered, like those of the mistletoe, with a viscous matter: but such dissemination seems to be effected more commonly by carpophagous birds, who carry them from one tree to another, or by the rain, that washes them from the upper to the lower branches of the same tree. There seems to be no doubt but that the *Myrmecodias* and the *Hydnophtums* are derived from Rubiaceæ that were primitively terrestrial or but feebly epiphytic. Their affinities with *Uragoga* are very strong. Usually epiphytic plants need for their development a small quantity of vegetable detritus in which their seed can be sheltered while germinating. Normal epiphytes are not provided, as are these Rubiaceæ, with fruits having viscous pulp that causes their seed to adhere to the surface of the bark upon which they fall, and would be unable to gain a lodgment on such a surface.

These Rubiaceæ seem, in fact, to be intermediate forms between the normal epiphytes and the parasites, such as the Loranthaceæ, which are likewise provided with viscous fruits (mistletoe) whose dissemination is effected by fruit-eating birds. The seeds of these Rubiaceæ are, at the time of their germination, peculiarly situated. Subject to desiccation, which is very likely to occur upon the surface of the bark, they can not borrow from the tree on which they rest the moisture necessary for their life, as do the plantlets of parasites. They must, therefore, create for themselves a store of water. This is done by the thickening of their hypocotylous axis, which enlarges into a tubercle that acts as a reservoir.

Beccari supposes that the formation of the flocculent tissue of the tubercle is a consequence of this mode of development combined with alternations of dryness and moisture. But this tissue develops from an internal generating layer, and, since it is composed of dead and dried cells, it seems more logical to suppose that it results from the starvation of such cells because of the formation about them of a corky layer that deprives them of all nutritive material and vascular connection. This would be an example of true parasitism of one tissue in relation to another, the generating layer acting like a parasite as regards the central parenchymatous layer.

Since Treub has not followed the complete evolution of a *Myrmecodia* from its germination up to its adult state, we may admit the opinion of Beccari until a formal demonstration of its error shall be furnished. According to this author, though the ants may not at the present time be necessary for the formation of the bulbiform enlargement of the hypocotylous axis, they are required for its future growth. To state

this in another way: The plantlets of *Myrmecodia*, without the help of ants, might, indeed, by reason of their hereditary tendencies, commence to form the tubercle but would be unable to develop to adult dimensions.

The intervention of ants must, then, be considered as indispensable to the life of the plant, since they contribute to the development of the organ that serves as a water reservoir. Were there no ants there would be no internal reserve of water, and the plant would be exposed to all the dangers of drought. It may be remarked here that, according to recent researches, a similar service is rendered to plants that grow in the sand of Sahara by nematode worms, that act on their subterranean organs. These worms (*Eterodera*, noted for their ravages on certain garden vegetables, particularly the betterave) cause a development of histological elements adapted to serve as water reservoirs.

The biologic relations of the ants with the *Myrmecodias* seem, then, to be symbiotic. The symbiosis is not, perhaps, as close as some think, but it seems difficult to deny its existence. There seems to be good reason to suppose that if, during several generations, the ants should cease to visit the tubercles, those bodies would undergo a progressive atrophy, or at least be reduced to the state of solid tubercles without internal cavities, such as those of *Pentapterygium* (*Vaccinium*) *serpens*, for example.

The lodging organs of several myrmecophilous orchids have a great resemblance to those of the Rubiaceæ we have just been studying. We know among the orchids three examples of which there can be but little doubt. One of these has been known for quite a long time, having been already mentioned by Rumphius. It is that of an epiphytous orchid, *Grammatophyllum speciosum*, whose pseudobulb thickens, even after the fall of the first leaves, and within whose fibrous mass ants establish themselves.

The *Lecanopteris deparioides* (a fern) has a rhizome similar to the tubercles of *Myrmecodia* and *Hydnophytum*, and which, like them, forms a true ants' nest. Within this rhizome there are hollowed-out cavities and galleries that are at first filled with a flocculent matter, analogous, doubtless, to that of the Rubiaceæ above cited. The ants penetrate the interior of this rhizome by an opening situated on the upper projecting part, upon which the fronds are inserted. The same arrangement is found in *P. sinuosum*, on the surface of whose rhizome are found circular openings, indeterminate as to situation, that seem undoubtedly to be the work of an ant (*Iridomyrmex cordata*), the same that inhabits *Hydnophytum petiolatum*.

Certain Melastomaceæ are likewise epiphytic and myrmecophilous. Such are the *Pachycentrias*, epiphytic or pseudo parasitic plants, whose branches, interlacing on the surface of tree trunks, give out a great number of adventitious roots. Upon these roots enlargements are found irregularly spherical in shape; and if, as frequently happens, sev-

eral such enlargements are contiguous on the same root, a chaplet is thus formed with more or less regular beads.

It is admitted that these tubercular roots may offer an asylum for ants. But the study of these tropical plants is as yet very incomplete. We can not even affirm that the tubercles are hollow. Many appear, when dry, to be full of spongy tissue, loosely arranged toward the center. We might be inclined to believe, with Beccari, that later this tissue is destroyed by ants, who thus hollow out a regular cavity within these tuberculous roots. But it should be noted that certain species of this genus have tubercular moniliform roots that are entirely solid, and only in certain specimens, even in species with hollow tubercles, do we find perforations allowing a communication between the inside and the exterior, which might, indeed, have easily been the work of ants.

The *Pachycentrias* do not seem to be provided with extra floral nectaries capable of attracting ants. The insects are, then, attracted to the plants only by the chance that they may be able to install themselves in the tubercle. But it should be noted that a type closely related to the *Pachycentrias*, *Pogonanthera robusta*, has a limbus prolonged at its base into two auricles, decurrent upon the petiole, that appear to be nectariferous. These nectaries attract ants, but the roots of these epiphytic plants are not, like those of the *Pachycentrias*, tuberculiform, but normal and incapable of affording lodgment to the ants attracted by the nectaries. This fact may, perhaps, give us a clew to the way in which biological relations were first established between the ants and the *Pachycentrias*. The ancestors of these latter plants were, without doubt, like the *Pogonantheras*, provided with extra-nuptial nectaries frequented by ants. These ancestors gave rise on the one hand to types that preserved the primitive features, as in *Pogonanthera*, and on the other to types better adapted to myrmecophilism, as in *Pachycentria*. The ants, impelled by their hereditary habits to visit those plants provided with foliary nectaries, continued to visit them even when those nectaries were undergoing atrophy. Profiting by the tendency of these plants to form tuberculous roots, they have progressively transformed these tubercles into ant nests, causing, by the irritation of their presence, a more marked hypertrophy of those organs. In a word, the *Pogonantheras*, utilizing the protection the ants afford against plant-eating animals, may have found it a real advantage to give those insects a mere asylum instead of offering them nutritive matters in the form of nectar. It is evidently an economy to the plant to offer simply a lodging to its defenders instead of both food and lodging, as does the *Acacia cornigera*, for example, and other plants that both feed and shelter the ants. If we accept this interpretation, which has only the value of an hypothesis, we would be led to regard the *Pogonantheras* as having economical myrmecophilous features. In the *Pogonantheras*, as in the myrmecophilous Rubiaceæ, the ants take up

their abode in swollen organs that act as water reservoirs, and consequently aid the plant against drought, which may become suddenly serious for any epiphyte.

The lodging organs of these plants appear to be purely of physiological origin. In other types they appear to have had primitively a parasitic origin. We have already spoken of the analogy between the tubercles of the myrmecophilous Rubiaceæ and certain galls. But it is more than doubtful whether the origin of these tubercles was primitively parasitic and traumatic. In the types of which we have yet to speak, parasitism, of animal origin, seems to have played an important part, even in certain cases a primordial one, in the formation of myrmecophilous organs.

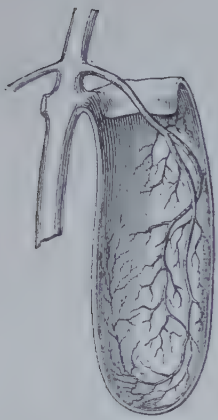
We will first fix our attention on the myrmecophilous features of *Dischidia.*

The *Dischidias* are Asclepiadaceæ of the farthest Orient. With flexible stems and branches they twine upon trees, and are especially noted for possessing appendages in the form of pitchers. These are generally pendent from the branches, and into them plunge adventitious roots that spring from the supporting peduncle (Pl. XXI). The resemblance of these pitchers to the galls produced on the leaves of various trees by aphides of the genus Pemphigus is such that a number of the early observers of these plants considered them as abnormal organs caused by the punctures of parasitic insects.

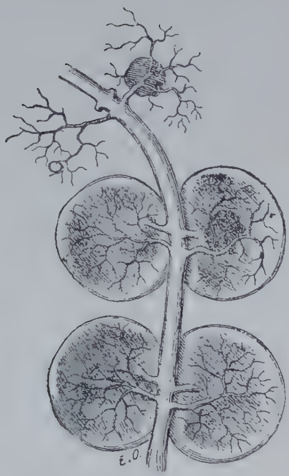
The morphology of these curious organs has been fully elucidated by the researches of Treub. They are modified leaves. The normal leaves of *Dischidia* are orbicular, thick, fleshy, and opposite. A pitcher is merely the blade of a leaf whose lower surface corresponds to the inner surface of the pitcher, and whose petiole is thicker than that of normal leaves. We can get a perfectly good idea of the formation of these organs by imagining the blade of a normal leaf to be folded toward the ground, then turned over and the borders brought together. There is, besides, a change of growth in the young developing pitcher, its increase being almost wholly along its middle, so that it takes the form of a hood, with its opening first turned downward, then becoming gradually set more or less upright.

The *Dischidias* have opposite leaves, but the normal leaf opposite the pitcher usually aborts. When the young urn takes on the form of an elongated flask, there are produced upon its petiole some adventitious roots, of which those arising near the mouth of the pitcher enter its cavity. A full-grown pitcher usually contains one or two long adventitious roots provided with a well developed system of radicles (fig. 1, Pl. XXII). The internal surface of these pitchers is purple, while their external surface is a grayish, glaucous green, like that of the surface of the stems and leaves.

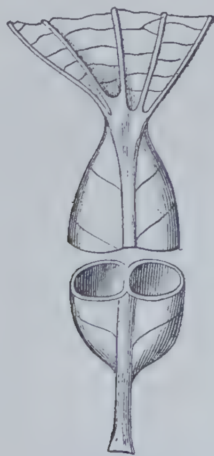
The direction assumed by the pitchers is variable and merits some attention. The greater number are hung vertically with the mouth



1. *Dischidia sp.*—Longitudinal section of an ascidium. (Delpino.)



2. *Conchophyllum sp.*—Portion of a branch viewed from its inferior aspect. (Delpino.)



3. *Tococa bullifera.*—Transverse section of the lodging bursa

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upward, but there are also some that are horizontal, and others erect with their closed extremities upward; that is to say, preserving the position they had during their formation.

The pitchers of the *Dischidias* are often inhabited by ants. Beccari has, for this reason, suggested that an irritation produced by insects (perhaps by ants) may have caused the abnormal evolution of these leaves that became transformed into pitchers. This deformation, in the first place accidental, may have became hereditary by the "indefinite and continual repetition of the phenomenon." Allow that the first cause of this abnormal evolution was parasitism, which is a tenable hypothesis, yet in the present condition of things there is nothing that would lead us to ascribe to the punctures or bites of insects any part in the formation of the pitchers. Whatever may be the part played by ants in this formation we may yet inquire if any biologic relations exist between them and the *Dischidias* whose pitchers they frequently inhabit. Other insects rarely enter the pitchers. The ants found there are always in good condition and generally in considerable numbers. The pitchers become true ant nests, sheltering some hundreds of individuals and many larvæ. The ants leave the pitcher with the same ease that they enter it, for it possesses no arrangement for retaining insects that have entered; on the contrary, the adventitious roots that traverse it from the petiole to the bottom form, with their numerous radicles, a sort of ladder leading to the outside of the flask. When we press a pitcher containing ants they leave it in great numbers, carrying their larvæ and their nymphæ. It should be noted that the *Dischidias* may, according to their situation, offer an asylum to ants, or grow, independent of any relations with them, yet presenting absolutely normal pitchers.

We might suppose, on examining these curious plants, that they ought to be classed as carnivorous, with *Nepenthes* and *Cephalotus* (Drude), whose foliary pitchers or ascidia are regarded as veritable traps for insects, capable of digesting their carcasses and absorbing the assimilable products of such digestion. This is not the place to discuss vegetable carnivorism, but it may be well to recall that in recent times the supposed digestive function of these ascidia has been ascribed wholly to the putrefactive bacteria that swarm in them as soon as they open (at least in the case of *Nepenthes*). The absorption of the soluble products of this digestion or putrefaction has yet to be demonstrated.

Wallich believed that the pitchers of *Dischidia* generally contain ants, of which the greater number are drowned in the dirty liquid, apparently rain water, that often half fills their cavity. Treub has shown that this liquid is not an exudation from the pitcher (contrary to an opinion advanced by Unger), its origin being wholly pluvial.

Admitting that, in certain cases at least (for example, during the torrential rains so frequent in the Tropics), ants may be drowned in the pitcher, would their soluble products, derived from the digestion,

bacterial or otherwise, of their carcasses, be useful to the plant—that is to say, absorbed? The internal walls of the pitcher are not at all suited for the absorption of liquids or the secretion of a digestive fluid. The absence of all kinds of glands is easy to demonstrate, and the entire surface of the epidermis is covered with a waxy coating. In addition, abundant stomata exist there which certainly does not indicate an organ for the absorption of liquids. This waxy coating is raised in minute turrets around each of the stomata, and the small chamber thus formed is constantly filled with air (Treub). These are features that contradict in the clearest manner the absorption of solid nutritive substances by the internal surface of the pitcher.

We may then suppose, with Delpino, that the ascidiferous *Dischidias* are not carnivorous plants in the strict sense of the word. Perhaps, then, the true function of the ascidia is "to prepare a liquid animal fertilizer for the purpose of nourishing the much ramifying adventitious roots that have introduced themselves into the pitchers." As a corollary we would have to admit that the pitchers belong to that class whose "immediate function is to kill by drowning the small animals that enter them."

Let us commence by examining this last hypothesis. If it be correct the pitchers ought all to contain liquid. Now, that is not the case, for, in the first place, a certain number have their openings placed horizontally or more or less reversed, and the walls of these are only moistened by the aqueous vapor transpired from the inner surface of the pitcher. In the pitchers that open upward there is but little water found, even after a day's rain. Their office as ant drowners appears, therefore, very problematic. Even the presence of the ants is not constant, as we have already said. In contrast to those of *Nepenthes* they are not arranged so as to retain the ants that may venture into them. Finally, what seems to settle the matter is that in most cases we do not find in them carcasses of drowned insects.

To these direct objections we are tempted to add another of an indirect character. Even granting that putrefaction might make soluble the carcasses that fall in abundance into the pitcher, it is doubtful whether the soluble products of that putrefaction would be directly absorbed by the rootlets (the root absorption of all organic substances, such as humic substances, being as yet one of the most controverted and controvertible points in vegetable physiology). It would, on the other hand, be highly improbable that the liquid fertilizer of the pitcher could take on, during the life of that organ, the various nitrite-producing fermentations whose products could be absorbed by the rootlets. This objection, which ought to be presented *a priori* together with the facts observed by Treub, convinces us that we ought to deny all carnivorous function, either direct or indirect, to the pitchers of *Dischidia*. Their true function is to aid the plant, which is of an epiphytic nature, to struggle against transpiration, which is often excessive. The impercep-

tible droplets in the interior of the pitcher may be reabsorbed by the slender radicles applied to its internal wall. The rain water gathered in the pendent pitchers evaporates slowly through the narrow mouth, and thus constitutes a reserve that may be absorbed by the rootlet.

The ants may, it is true, be indirectly useful to the plant by protecting it against the attacks of phytophagous creatures. The pitcher presents, indeed, various features favorable to the life of the ant. In particular, the rain water, which does not enter in sufficient quantities to become dangerous to the inhabitants, may probably be to their advantage, for the ants that inhabit these pitchers are fond of water. But the only protection the ant can offer in exchange for the shelter afforded by the plant is that which we have before mentioned. Even in this connection "nothing authorizes us to suppose that the colonies of ants exercise a salutary influence upon the plant" (Treub). Indeed, the ants when they multiply too greatly in a pitcher gnaw the rootlets, or, indeed, cause their malformation. Still, Beccari has seen the *Dischidias* form inextricable masses of pendent branches on the surface of trees, which masses were so well defended by the ants and termites that inhabit them that it was impossible to put the hand upon them.

If at the present time the ants play no part in the normal evolution of the leaves that become pitchers, they yet may have had something to do with their original formation. In a related genus, *Dischidia-Conchophyllum*, and in many species of Dischidia, all the leaves are indistinctly suborbicular or reniform, convex on one face, concave on the other, like a watch crystal, and applied against the bark of the tree that serves them for support. Their inferior concave face is purple (fig. 9, Pl. XXII). At the level of the leaves the branches give off adventitious roots, very much ramified and sheltered under the concavity of the leaves. These roots, arising near the insertion of the petioles, divide dichotomously and serve, some to cause the plant to adhere to the bark of the tree it inhabits and to absorb the nutritive matter they may find there, others, covered by the leaves, to absorb water, for which they are more especially designed.

The ascidiferous Dischidias are certainly derived from types with reniform leaves like those we have just described. Now, the inferior face of these concave leaves is often inhabited by acarids, and we may suppose, with Beccari, that the irritation produced by these parasites has caused a more marked concavity in the organ that shelters them. There would be primitively formed there true galls, and the deformation of the leaf might become hereditary in the course of time. Ants, finding shelter under these concave leaves applied to the surface of the trees, have chosen a domicile there, profiting thus by an organ of lodgment whose abnormal evolution may have had for its primordial cause the adaption of the plant to the struggle against drought or parasitism, or perhaps both causes combined. As soon as they were installed under these lodging organs, the ants became useful to the plants by

accumulating, in these recesses, organic detritus capable of furnishing assimilable soluble substances to the rootlets sheltered under the concave leaves. The irritation caused on the under surface of the leaves by the presence of the ants may have resulted in the augmentation of the cavity of the organ and thus led it to take on the form of a pitcher. The parasitic origin of the lodging organs is doubtful in the *Conchophyllums* and the *Dischidias.*

This is not the case with the lodging organs of the *Melastomaceæ*. In this family a great number of American types have leaves provided, at the base of the limbus, with organs suitable for the lodgment of ants. Such are the genera *Lococa*, *Myrmedone*, *Majeta*, *Microphysca*, and *Calophysca*. It was Aublet, the old explorer of French Guiana, who first remarked one of the Melastomaceæ that presented these curious features. He says, speaking of the *Tococa guianensis* "the leaves are each attached to their stems by a little pedicle, that is at first grooved on its upper surface, convex below, and set with hairs, but its two sides afterwards enlarge and form a double bladder having the form of a heart. This bladder is provided with two holes placed at the lower part of the leaf underneath, between the two intermediary nervures. It is by these two holes that the ants enter and leave each division of the bladder and as the stems are hollow they can penetrate them also by means of openings that they make, and this is the reason why some of the natives have given this plant the name of the ants-nest, it being, as one may say, continually covered with them."

He notes a similar arrangement in the *Majeta guianensis*, of which he says "the leaves have on their under surface five longitudinal nervures and numerous transversals. They are attached by a short pedicle that, together with the lower part of the leaf, is enlarged in the shape of a bladder, divided into two cavities by a median partition. The body of the bladder is much more raised above than below. The small leaves do not usually have it." This last point is of the highest importance. It seems to show that the presence of ants on the interior of the sac causes an hypertrophy of the inhabited leaf that is far from being prejudicial to it. Of the two opposite leaves of each pair one is vesicular at the base, the other and smaller one is not so. But before admitting that the ants cause an hypertrophy of the foliary tissue we should ascertain whether the inequality of size in the two leaves is not anterior to the occupation of the vessel by these insects. It is true, however, that even if this latter fact were verified we might admit that primitively the ancestors of the Melastomaceæ were provided with equal opposite leaves having a tendency to form a vesicle at the base of the limbus. When this vesicle was once visited by the ants the irritation produced by them would cause its hypertrophy and the more considerable afflux of nutritive material thus occasioned would lead to an increase in growth of the entire leaf. This hypertrophy would then be hereditarily transmitted and would to-day be observed, even at an

early age, independently of the action of the ants. But it will always be pertinent to ask why the ants did not cause the hypertrophy of both the opposite leaves which ought *a priori* to be subject to the same conditions as to the formation of vesicles. May it not be that primitively without any intervention on the part of ants, there was a tendency to an inequality of development between the two opposite leaves of the same pair, as is seen in a number of vegetables that have opposite leaves? The favored leaf would tend to form a vesicle which the unfavored leaf could not do. This difference of size between the two leaves of the same pair is still more marked in the *Myrmedone macrospermum* of Brazil and the *Calophysca heterophylla* of Peru.

In *Tococa truncata* the foliary bursa is not much developed, but usually larger on one of the leaves than on its opposite. The inequality of the same pair is very well marked in *T. platypetala* and *T. bullifera*. In this last species the development of the limbus seems to be proportional to that of the bursa. In the section *Epiphysca* of the genus *Tococa* the bursa is evidently formed at the base of the limbus. In the section *Hypnophysca* it seems to be produced from the petiole, but in reality it is the limbus that is decurrent along the petiole and forms there an elongated bursa. The fact is clearly shown in *Tococa bullifera* (fig. 10). The bursæ of *Tococa formicaria*, *T. guianensis* and *T. platypetala* are very fine. The stem of *T. guianensis* and *formicaria* seem to be hollow.

The relation between the size of the limbus and that of the bursa leads us to suspect that the internal surface of the bursa may be endowed with absorbent properties. If the bursa played the part of a true absorbing organ it would yield to the limbus nutritive material, which would explain why a leaf possessing a larger bursa also posesses a larger limbus. In dried specimens we find in the bursa a large quantity of detritus. The internal surface of *T. formicaria* and *T. guianensis* bristles with papillæ and hairs. In the first species we find there scale-insects as well as ants.

Beccari found entire colonies of ants with pupæ on single specimens of *T. bullifera* and *Myrmedone macrosperma* of Brazil and Venezuela. These plants have bursæ at the base of the limbus, which appear more complete than those of other species. The transverse nervures that run over them project on the inner surface as lamellæ that indirectly divide the bursa into galleries, as in the tubercle of the *Hydnophytums*.

In *Majeta guianensis* the internal wall of the bursa is lined with elongated papillæ formed of cells normally filled with a colored protoplasm that seems analogous to the foliary glands of *Drosera*. This fact, together with the presence of fragments of ants and other insects, has led Beccari to suppose that the bursa may in this case have digestive and assimilative functions.

Some species of *Tococa* have leaves destitute of bursæ. In others (*T. subnuda*) the bursæ are rudimentary. The examination of this

species is very instructive from the point of view of the genesis of these foliary bursæ. In this species, on the under surface of the limbus near its base, in the angle formed by the median nervure and the two lateral primary nervures, there may be observed small cavities surrounded by hair. The analogy of these organs to the acaro-cecidia (that is to say, to galls caused by certain acarids) of laurels and various other plants is striking. If we conceive such an organ increasing in size without enlarging its orifice we will obtain exactly the foliary bursa of the above-cited Melastomaceæ.

The galls of laurels and some other plants, *Viburnum lucidum*, for example, are inhabited by acarids. It is not irrelevant to recall here that these acaro-domatias (to use the expression of Lundström) are by no means pathological productions injurious to the plant. The acarids that cause them render, on the contrary, eminent services by clearing the plant of the spores of parasitic or saprophytic fungi found on the snrface of the leaves. There is, then, no improbability in supposing that primitively the foliary bursæ of the Melastomaceæ have been acarid galls in which the ants sought an asylum provisionally. Finding the dwelling suitable, they installed themselves there permanently, and the irritation of the plant caused by them may have occasioned the ensuing hypertrophy of the bursæ. In the Melastomaceæ the lodging organ seems to be undoubtedly of parasitic origin.

Let us now attempt to extract from this mass of facts some general views.

Primitively the relations between ants and plants were as simple as possible—those of the eaters and the eaten. Such are at the present time the relations of the harvester ants, especially of the leaf cutters, to the plants which they despoil. But we should note that already the plants from which the ants harvest obtain some advantages from that harvesting. A number of seeds are sacrificed, but some, escaping the voracity of the ants, are disseminated by them and thus truly aided by those insects in their struggle with rival species for existence. From this dissemation, at first accidental, comes the normal mimicry of the cocoons of ants shown by some seeds.

As the industry of the ants becomes more developed they no longer content themselves with merely gathering vegetable products. They undertake agriculture, and the plants cultivated by them are, by the very care they receive, favored in their struggle with rival species, as are cereals cultivated by man, which have no longer to struggle with indigenous species. A number of ants also content themselves with sugary liquids, such as honeydew and nectar. Primitively they seem to have been satisfied to gather the honeydew diffused on the surface of leaves; afterwards their suction, localized at special points upon the foliaceous organs, may have led to the formation of extra floral nectaries. These organs may have served the plant in two ways—first, by attracting to its surface ants that would protect it against phytophagi;

second, by diverting from the reproductive organs ants that otherwise, in certain flowers, might steal the nectar, thus depriving winged insects of it without aiding in pollination.

But the protection of the floral nectaries may be assured by other arrangements still more efficacious and more economical for the plant. By becoming myrmecophobic and keeping its floral nectaries away from the ants the plant economizes its nutritive materials. Chevaux de frise, slippery surfaces steep peduncles, and viscous hairs are the principal myrmecophobic features.

We may consider as a true animal honeydew the sugary excretion of plant lice, cochineals, and some other insects. From this arise the pastoral habits of ants, the establishment of subterranean and aerial stables, and the effective protection of the plant lice against their enemies; hence occurs a real injury to a number of plants indirectly caused by ants.

The instinct of ants leads them to lodge themselves in some cavities capable of offering them shelter. These cavities will be more advantageous to them in proportion as they are within reach of the food they require. So, if a nectariferous plant visited by ants has a suitable cavity, it will soon become a lodging plant for those insects. Such is also the case with a nonnectariferous plant inhabited by insects capable of furnishing nectar to ants. The ants will then occupy themselves with the rearing of such animals within the lodging cavity. In certain cases, also, when a plant finds a real advantage in the constant presence of ants on its surface, it will differentiate "food bodies" suitable for furnishing them with a more abundant aliment.

The services rendered to plants by ants are of various kinds. In a number of cases the latter effectually protect the host plant against the attacks of parasitic insects or the teeth of herbivora. In the case of lodging plants with cavities arranged for stables the ants may minimize the injuries inflicted by plant lice and cochineals by transporting them from young organs, where their presence would be injurious, to localities upon the vegetable where their presence would be more compatible with the life of the plant. There is thus established a sort of triple symbiosis, the ants protecting their flocks that furnish them food and diminishing the injuries occasioned by those flocks upon the plant on which they feed. Sometimes, but rarely, the detritus accumulated by the ants in the lodging organ seems to serve as a nutritive material for the plants. This, however, remains to be demonstrated in most cases. Finally, the irritation caused by the ants upon the lodging organ may, by determining a greater increase in its growth, assist the plant in its struggle with rival species or with physical agencies.

The primitive origin of the lodging organ varies, in fact, in different types. Sometimes the ants make use of closed or nearly closed cavities forming a part of the morphologic plan of the plant, and having a merely mechanical function (hollow internodes, being lighter, economizing

material and at the same time strengthening the structure); sometimes they lodge in organs that protect plants against herbivora (spines) or against physical agencies (water reservoirs); finally, in certain cases, the parasitic origin of the lodging organ seems unquestionable, it representing a real cecidium or gall.

In certain types the ants seem to have adapted the lodging organ to their own needs (by perforating the wall, by forming galleries); in others, features at first abnormal, caused by the presence of ants, seem by heredity and selection to have become normal, after which the insects find lodgings ready for occupation without the necessity for preparatory labor.

Myrmecophilous features may, then, vary in their origin, according to circumstances.

The biologic relations between plants and ants thus tend, by insensible degrees, to assume the complex, reciprocally advantageous conditions of communal life; that is to say, of symbiosis.

Looking at the phenomena of nature from the point of view of the older naturalists, we should certainly go into raptures over the varied means she employs to reach her ends. Were we to examine the relations between plants and ants, as do those philosophers who seek final causes for all biologic phenomena, we could not too much admire the prevision of nature in putting within reach of those insects plants for their nourishment, and in giving certain plants, in return for certain small advantages granted, inhabitants capable of protecting them.

But to our modern eyes the relations of living things, in the midst of seemingly peaceful nature, appear in a somber light. Attack and defense are their essential controlling conditions. *Homo homini lupus*, said the philosopher; and the race of man is no worse than other living species in its struggle for existence. All beings seem to have but two aims: reproduction and destruction. Growth of the individual leads to reproduction, indefinite multiplication of the species at the expense of its neighbors, and the ruthless destruction of rivals. Does it not seem as if each species was created for the extermination of some other, and that soon the struggle of so many individuals of opposing tendencies must result in the extinction of every living thing on the globe?

But, strange to say, from this very contest arises accord; the antagonism of living beings results in symbiosis; instability in equilibrium; death in life. Chaos engenders order. The result of these tremendous struggles, though usually inappreciable by the unsuspecting eye, may be summed up in one word: harmony. A perfect accord is established between creatures having nothing in common, precisely because of the diversity of their needs; for in this accord the copartners have no interest in despoiling their associates.

Thus there is certainly confirmed, for life in general, the law of progress. Disregarding the sufferings and death of individuals, evolution tends to establish between beings primitively rivals a *modus vivendi*

that assures the free expansion of the species; a progressive expansion that must soon find its limits in the new struggle that species, triumphing by their union, must make against neighboring species.

What horizons does the study of ants open to the naturalist! The investigation of their relations to plants is capable of giving to those who undertake it the most lively pleasure that the naturalist can enjoy. Those who have succeeded in raising this little corner of nature's veil will acknowledge that they owe the ants a debt of gratitude. And if I have succeeded, by this somewhat dry exposition, in securing your kind attention, is it not to these little creatures that I owe it?

SOME QUESTIONS OF NOMENCLATURE.[1]

By THEODORE GILL.

INTRODUCTION.

I had originally selected for the address which it is my duty and privilege to give to-day a very different subject[2] from that which I am now to discuss, but the renewed and lively interest which is being manifested at present in the ever-troublous subject of nomenclature has led me to take it as my theme. I have been especially influenced, too, by the consideration that a committee was appointed at the last zoological congress, held at Leyden, to consider the subject, and suggestions have been asked for.[3] Of the multitudinous questions that offer for review, time will only permit us to examine a few.

Nomenclature, in the modern sense of the word, did not trouble naturalists till near the middle of the last century. The animals and plants of the ancient world were mostly treated of under the names which the Greeks or Romans had used, or were supposed to have used. The forms that became first known after the discovery of America were introduced into the literature under names more or less like those which they bore among the aboriginal inhabitants of the countries from which those forms had been obtained. Only a few names were coined from the Latin or Greek, and used for forms not mentioned by classical authors. Examples of such are *Ammodytes* and *Anarrhichas*, invented

[1]Address by vice-president of section F (Zoology) at Buffalo meeting of the American Association for the Advancement of Science, August, 1896. Printed in Science, October 23, 1896, and in Proceedings of the Association, January, 1897.

[2]Animals as Chronometers for Geology.

[3]The Third International Zoological Congress (Leyden, Sept., 1895) appointed an international commission of five members to study the various codes of nomenclature in use in different countries. This commission is composed of Dr. Raphael Blanchard (France), Professor Carus (Germany), Professor Jentink (Holland), Dr. Sclater (England), and Dr. Stiles (United States). Dr. Stiles requested the appointment of an American advisory committee. This advisory committee has now been completed and is made up as follows:

"Dr. Gill, representing the National Academy of Sciences; Dr. Dall, representing the Smithsonian Institution; Professor Cope, representing the Society of American Naturalists; Professor Wright, representing the Royal Society of Canada; Professor Packard, representing the American Association for the Advancement of Science."

by Gesner. But none of those names were employed as true generic designations. Genera, in fact, in the strictest sense of the word, were not used, by zoologists at least,[1] till the time of Linnæus.

There were certainly very close approximations to the idea manifest in some of the older authors, such, for example, as Belon and Lang;[2] but their analogous groups were not strictly defined and limited, as the genera of Linnæus and his followers were. The system has been one of slow growth, and has developed in accordance with our knowledge of nature and in response to the need for expressing the various degrees of complication of the organisms. The species known to the naturalists of early times were few in number—at least, comparatively—and the old students had no idea of the excessive diversity of form and structure familiar to us.

A census of animals and plants was taken by Ray shortly before Linnæus commenced his career, and enumerated less than 4,000 animals, exclusive of insects; and of those it was estimated that there were about "20,000 in the whole world." He evidently believed that the entire number living would not be found greatly to exceed this. But let Ray speak for himself.

According to the author's classification, animals were divided into four orders—"beasts, birds, fishes, and insects." The number of beasts, including also serpents, that had been accurately described he estimated at not above 150, adding that, according to his belief, "not many that are of any considerable bigness, in the known regions of the world, have escaped the cognizance of the curious." (At the present day more than 7,000 species of "beasts," reptiles, and amphibians have been described.[3]) The number of birds "may be near 500, and the number of fishes, excluding shellfish, as many; but if the shellfish be taken in, more than six times the number." As to the species remaining undiscovered, he supposed "the whole sum of beasts and birds to exceed by a third part and fishes by one-half those known." The number of insects—that is, of animals not included in the above classes—he estimated at 2,000 in Britain alone, and 20,000 in the whole world. The number of plants described in Bauhin's "Pinax" was 6,000, and our author supposed that "there are in the world more than triple that number, there being in the vast continent of America as great a variety of species as with us, and yet but few common to Europe, and perhaps Africk and Asia. And if on the other side the equator there be much land still remaining undiscovered, as probably there may, we must suppose the number of plants to be far greater. What," he continues, "can we infer from all this? If the number of

[1] The genera of plants in Tournefort's work are perfectly regular, as well as defined and illustrated, but the nomenclature is certainly not binominal.

[2] Lang was by no means a binomialist. See note on p. 460.

[3] In a recent estimate of described species, 2,500 species of mammals are enumerated and 4,100 species of reptiles and amphibians, the several classes thus aggregating 6,900. This is probably an underestimate.—P. Z. S., 1896, 306.

creatures be so exceeding great, how great, nay, immense, must needs be the power and wisdom of Him who formed them all!"

About 375,000[1] species of animals are now known, and of insects we still know the smaller portion.[2]

As knowledge of species of animals and plants increased, the necessity of system in registering them became apparent. Linnæus and Artedi especially appreciated this necessity, and early applied themselves to the correction of existing evils and the reformation of the classification and nomenclature of all the kingdoms of Nature. The Latin language had been long the means of intercourse among the learned, and was naturally selected as the basis of nomenclature. Instead of Latin words used as equivalents or translations of vernacular, by Linnæus and Artedi they were taken especially and primarily for scientific use. The various *kinds* of animals became the more exact *genera* of naturalists. A new language, or rather vocabulary of proper names, was developed with the Latin as the basis. As no adequate idea was at first had of the magnitude of the subject, rigorous codes of laws were formulated on the assumption that philological questions were involved rather than the means for the expression of facts. But soon the bonds that had been framed for the restriction of the new vocabulary were broken. The idea dawned upon men that they had to do with natural objects rather than philological niceties, and that which was most conducive to facile expressions or exhibitions of facts was more to the purpose than Priscianic refinements. Linnæus himself eventually refused to be bound by the laws which he had originally framed. The early companion of Linnæus—Artedi—who had cooperated with him, and also framed a similar code for ichthyology especially, was prematurely lost to science. The fact that Artedi devised the first code of laws affecting zoology has been generally overlooked, and a few of his "canons" may be noticed here. The extent to which each one of the two—Linnæus and Artedi—influenced the other can not now be learned, nor will it be necessary to consider here who of the two was the abler naturalist. It must suffice that there was almost perfect agreement between Artedi and Linnæus in the spirit of the laws they respectively framed.

COMMENCEMENT OF BINOMIAL NOMENCLATURE.

The question that has been most agitated of late is, what time shall we recognize as the starting point for the binomial nomenclature? Even now not all will be bound by any such limit for generic nomenclature; but those who will are divided into two main camps, those who

[1] A census of animals recently taken under the superintendence of Dr. Sclater gave 386,000 species. P. Z. S., 1896, 307.

[2] The late Dr. C. V. Riley even went so far as to say "that there are 10,000,000 species of insects in the world would be, in [his] judgment, a moderate estimate." The largest previous estimate, by Sharp and Walsingham, 2,000,000, was termed by Riley "extremely low."

start from the tenth edition of the Linnæan "Systema Naturæ," published in 1758, in which the binomial nomenclature was first universally applied, and those who advocate the twelfth edition of the "Systema," published in 1766, the last which appeared during the life of Linnæus.

But it may be premised here that even the fact that Linnæus was the first to devise the system of binomial nomenclature is not conceded by all. It has been claimed that about two centuries before Linnæus published his "Philosophia Botanica," Belon had uniformly and consistently applied the binomial nomenclature to plants as well as animals, fishes, and birds.[1] It has been also urged that C. N. Lang (Langius),[2] in 1722, used the binomial nomenclature for shells. I have not been

[1] Crié (Louis). Pierre Belon et la nomenclature binaire. Rev. Sc., xxx, 737–740, 9 Dec., 1882.

[2] My efforts to see a copy of Lang's "Methodus nova Testacea marina in suas Classes, Genera, et Species distribuendi" (Lucern., 1722) have not been successful. Maton and Rackett say that "he is the first whose generic characters are founded on commodious distinctions, but expressly state that "there are no trivial names." (See Trans. Linn. Soc., vii, 156, 157.) He may have properly appreciated genera.

This note was the result of consideration of statements made by Dr. Raphael Blanchard in his excellent "Rapport présenté au Congrès International de Zoologie," published in the "Bulletin de la Société Zoologique de France pour l'année 1889." The statements were made therein (p. 262) that Tournefort had originated the binomial nomenclature (C'est à Tournefort que revient sans conteste la gloire d'avoir fondé la nomenclature binaire) and that among others Lang had followed him (L'example était donné: Lang et Klein appliquent cette méthode à la description des mollusques). It was also specifically stated (p. 264) that zoological nomenclature was initiated by Lang (la nomenclature zoologique ne commence réellement qu'en 1722, avec Lang).

Since the publication of the address I have been able to examine Lang's work, and do not find that the contention in the report cited is sustained. Lang divided the marine shells among three parts (non-turbinate univalves, turbinate univalves, and bivalves); each part (pars) is divided into classes, a class (classis) into sections, and a section (sectio) into genera. One series will fairly illustrate all.

Class 4 (Classis IV) is named "Strombi" and is divided into two sections: "Sectio I. Strombi ore superius aperto" and "Sectio II. Strombi integri." The first section is disintegrated into six genera: "Genus I. Strombi canaliculati acuminati," "Genus II. Strombi canaliculati rostrati ore simplici," "Genus III. Strombi canaliculati rostrati ore anguloso," "Genus IV. Strombi canaliculati rostrati ore labioso," "Genus V. Strombi sulcati vulgares," and "Genus VI. Strombi sulcati ore labioso." The species are named accordingly, those of "Genus I" being designated as follows:

"Strombus canaliculatus acuminatus *laevis ore denticulato vel striato.*

"Strombus canaliculatus acuminatus *striatus.*

"Strombus canaliculatus acuminatus *striatus & granulatus.*

"Strombus canaliculatus acuminatus *striatus & transversim per modum striarum quasi sulcatus.*"

And so on with the others.

The generic name in each case here reproduced is indicated by roman type and the specific by italics. Instead of an uninomial generic name there is a generic term of three words in each case, and the specific name is of the nature of a diagnosis.

With these examples it must be evident that a different meaning has been attached by Dr. Blanchard to binomial nomenclature (nomenclature binaire) from that entertained by the present writer, or that the learned author has based his statements on erroneous information.

able to confirm either statement, and therefore have to side with the great majority who accord to Linnæus the credit of that achievement.

Almost all the naturalists of the United States accept 1758 as the starting time for nomenclature, and now most of the naturalists of Europe take the same view. But the English generally accept 1766 for the commencement of their orismology. It was "after much delibera tion" that the committee of the British Association for the Advancement of Science determined on the edition of 1766. It was only because that edition was "the last and most complete edition of Linné's works, and containing many species that the tenth did not," that it was so selected—surely an insufficient reason. A principle was subordinated to an individual.

Logically, the actual period for the commencement of the binomial nomenclature should be when the rules for that nomenclature were distinctly formulated; and that was 1751, when the "Philosophia Botanica" was first published. Practically, however, it makes little difference for most classes,[1] whether we take that date or 1758, when the next succeeding edition of the "Systema" was published. But it does make much difference whether we take the tenth or twelfth edition. There is really no good reason for keeping Linnæus on that lofty pedestal on which he was enthroned by his disciples of a past century. His work does not justify such an elevation. In every department of zoology contemporaries excelled him in knowledge and in judgment. May we not hope that, ultimately, this truth will be recognized, and the tenth edition universally accepted for the first work of the new era?

TRIVIAL NAMES.

The binomial system has come into prominence through a sort of developmental process. Although now generally regarded as the chief benefaction conferred by Linnæus[2] on biology, it was evidently considered by him to be of quite secondary importance.

The first extensive use of it occurs in the Pan Suecicus, published in 1749, where the author mentions that to facilitate the recording of his observations he had used an "epithet" in place of the differential character.[3] It was thus a mere economical device for the time being.

[1] Arachnology would be most affected, for Clerck's work was published in 1757.

[2] Linnæus himself did not claim this as an improvement in his account of the advancement he had effected in science.

[3] Possumus nunc ultra duo millia experimenta certissima exhibere, quæ sæpe decies, immo sæpe bis decies sunt iterata. Si autem sumamus Floram Suecicam *Holmiæ*, 1745, & ad quamlibet herbam, ut chartæ parcatur, nomen adponimus genericum, numerum Floræ Suecicæ & epitheton quoddam loco differentiæ, negotium in compendium facile mittitur.—Pan Suecicus, pp. 228, 229.

This thesis is attributed to Nicolaus L. Hesselgren in some bibliographies, and naturally so, as it bears his name in the title; but Linnæus probably did not claim more than his own in claiming the authorship, although Hesselgren apparently wrote part of it himself. It is sometimes difficult exactly to fix the authorship in the case of some of the old theses.

In the Philosophia Botanica he also treats it as a matter of minor importance. He distinguishes between the specific name and the trivial.

His specific name corresponds to what we would call a diagnosis (nomen specificum est itaque differentia essentialis); his trivial name is what would now be called the specific.[1] It is merely suggested that trivial names may be used as in his Pan Suecicus, and should consist of a single word taken from any source.[2]

This system was fully carried out in the succeeding editions of the Systema Naturæ. Both names were then given—the nomen specificum after the number of the species, under each genus, and the nomen triviale before the number, in the margin.

Linnæus placed little store on the trivial names, and accredited such to old botanists; but he took special credit for specific names (or diagnoses), claiming that none worthy of the title had been given before him.[3]

DRACONIAN LAWS.

For generic nomenclature a Draconian code was provided by Linnæus and Artedi. It is now a maxim of good legislation that excessive severity of law is apt to defeat the object sought for, and the tendency of civilization is to temper justice with mercy. So has the tendency of scientific advancement been toward a mitigation of the Linnæan code. Nevertheless, its severity is more or less reflected in later codes—even the latest—and therefore a review of some of these old canons will not be entirely a resurrection of the dead, and may contain a warning for the future.

In exclusiveness for generic names Linnæus and Artedi went far ahead of any of the moderns. They provided that no names were available for genera in zoology or botany which were used in any other class of animals or plants, or even which were used for minerals, tools, weapons, or other instruments, or even places.[4]

[1] 257. Nomen specificum *legitimum* plantam ab *omnibus* congeneribus (159) distinguat; *Triviale* autem nomen legibus etiamnum caret.—Phil. Bot., p. 202.

[2] NOMINA TRIVIALIA forte admitti possunt modo, quo in *Pane suecico* usus sum; constarent hæc

Vocabulo unico:

Vocabulo libere undequaque desumto.

Ratione hac præcipue evicti, quod differentia sæpe longa evadit, ut non ubique commode usurpetur, & dein mutationi obnoxia, novis detectis speciebus, est, e. gr. Pyrola [5 sp.]

Sed nomina Trivialia in hoc opere seponimus, de differentia unice solliciti.—Ph. Bot , pp. 202, 203.

[3] Trivialia erant antecessorum & maxime Trivialia erant antiquissimorum Botanicorum nomina.

Character Naturalis speciei est *Descriptio: Character* vero *Essentialis* speciei est *Differentia.*

Primus incepi Nomina specifica Essentialia condere, ante me nulla differentia digna exstitit.—Ph. Bot., p. 203.

[4] Nomina piscium generica. quæ quadrupedibus pilosis, avibus, amphibiis, insectis, plantis, mineralibus, instrumentis opificum, etc., communia sunt, omnino deleantur. Linn. Fund. 230.—Art. Ph. Ich., § 193.

Under this rule such names as *Acus*, *Belone*, *Citharus*, *Hippoglossus*, *Lingula*, *Novacula*, *Orbis*, *Orca*, *Remora*, *Solea*, and *Umbra*—all now or sometime in common use—were specified.

This rule was soon relaxed, and any name not previously used in zoology, or, at most, biology, was considered admissible.

Another rule sends to Coventry all names composed of two names of different animals, because it might be uncertain to which genus an animal really belongs.[1] The ancient name "Rhino-Batus" is even mentioned as one of the delicts.

This rule is also without any justification, and the reason given for it baseless. Compound words of the kind exiled are in entire harmony with the genius of the classic languages. As an illustration of their use among the Greeks, we need refer to one group only—that is, compounds with hippos, as *Hippalectryon*, *Hippanthropos*, *Hippardion*, *Hippelaphos*, *Hippocampos*, *Hippotigris*, and *Hippotragelaphos*. (*Hippokantharos*, *Hippomurmex*, *Hippopareos* and *Hipposelinon* are other classic Greek words, but do not belong to the same category as the others, inasmuch as they were used in a sense analogous to horse-chestnut, horse-mackerel, and horse-radish with us, the word "horse" in this connection conveying the idea of strength, coarseness, and bigness.)

In another rule, all words are proscribed as generic names which are not of Latin or Greek origin;[2] and among the proscribed are such names as *Albula*, *Blicca*, *Carassius*, and many others, which were later used by Linnæus himself as specific names, and which are now used as generic denominations.

Words with diminutive terminations were barely tolerated, if admitted at all,[3] and the reason alleged for such treatment was that the cardinal name might belong to another class. Among the examples named were *Anguilla*, *Asellus*, *Leuciscus*, *Lingula*, *Oniscus*, and *Ophidion*, now familiar in connection with some of our best-known genera. One of these—*Ophidion*—was subsequently used by Linnæus himself as a generic name.

All are now tolerated without demur even, and probably by most naturalists were never supposed to have been tainted with offense of any kind. For all such words we have also classical examples; and four have already been named—the *Oniscus* and *Ophidion* of the Greeks, adopted by the Romans, and the *Anguilla* and *Asellus* of the Latins.

Generic names, derived from Latin adjectives, were also declared to be unworthy of adoption.[4] *Aculeatus*, *Centrine*, and *Coracinus* were cited as examples of words that should be rejected under this rule. Later

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[1] Nomina generica, ex uno nomine generico fracto, et altero integro composita, exulent. Linn. Fund. 224.—Art. Ph. Ich., § 196.

[2] "Nomina generica, quæ non sunt originis Latinæ vel Græcæ, proscribantur. Linn. Fund. 229." Art. Ph. Ich., § 198.

[3] "Nomina generica diminutiva vix toleranda sunt. Lind. Fund. 227." Art. Ph. Ich., § 202.

[4] "Nomina generica imprimis Latina pure adjectiva, sed substantive usurpata, criticorum more improbanda sunt. Linn. Fund. 235." Art. Ph. Ich., § 204.

writers have repeated the denunciations uttered by Linnæus and Artedi, and refused to adopt such words. But hear what Plutarch says of names of men derived from adjectives.

In his life of Coriolanus, Plutarch, in recounting the events subsequent to the capture of Corioli, and the refusal of Marcius to accept more than his share of the booty, comes to the proposition of Cominius.[1]

Let us, then, give him what is not in his power to decline; let us pass a vote that he be called *Coriolanus*, if his gallant behavior at Corioli has not already bestowed that name upon him. Hence came his third name of Coriolanus, by which it appears that Caius was the proper name; that the second name, Marcius, was that of the family; and that the third Roman appellative was a peculiar note of distinction, given afterwards on account of some particular act of fortune, or signature, or virtue of him that bore it. Thus, among the Greeks additional names were given to some on account of their achievements, as *Soter, the preserver*, and *Callinicus, the victorious;* to others, for something remarkable in their persons, as *Physcon, the gore-bellied*, and *Gripus, the eagle-nosed;* or for their good qualities, as *Euergetes, the benefactor*, and *Philadelphus, the kind brother;* or their good fortune, as *Eudæmon, the prosperous*, a name given to the second prince of the family of the Batti. Several princes also have had satirical names bestowed upon them: Antigonus (for instance) was called *Doson, the man that will give to-morrow;* and Ptolemy was styled *Lamyras, the buffoon.* But appellations of this last sort were used with greater latitude among the Romans. One of the Metelli was distinguished by the name of *Diadematus*, because he went a long time with a bandage, which covered an ulcer he had in his forehead; and another they called *Celer*, because with surprising celerity he entertained them with a funeral show of gladiators a few days after his father's death. In our times, too, some of the Romans receive their names from the circumstances of their birth; as that of *Proculus*, if born when their fathers are in a distant country; and that of *Posthumus*, if born after their father's death; and when twins come into the world, and one of them dies at the birth, the survivor is called *Vopiscus.* Names are also appropriated on account of bodily imperfections; for among them we find not only *Sylla, the red*, and *Niger, the black*, but even *Cæcus, the blind*, and *Claudius, the lame;* such persons, by this custom, being wisely taught not to consider blindness or any other bodily misfortune as a reproach or disgrace, but to answer to appellations of that kind as their proper names.

What was good enough for the ancient Romans to bestow on the most admired of their heroes is good enough for the nomenclature of our genera of animals. We have also examples of names of adjective form used substantively for animals among classic writers. Such, for example, are the *Aculeatus* (pipe-fish) and *Oculata* (lamprey or nine-eyes), mentioned by Pliny.

Linnæus himself, later, coined many names having an adjective form; and three of his genera of plants of one small family, so designated, occur in this region—*Saponaria*, *Arenaria*, and *Stellaria.* Yet even at the present day we have evidences of the lingering of the old idea embodied in the canon in question.

[1] Laughorne's translation of Plutarch's Lives is quoted from.

We have also had drawn up for us certain rules for the conversion of Greek words into Latin, which are tinctured with more than Roman severity. Thus, we are told that Greek names ending in *-os* should always be turned into *-us;* that the final *-on* is inadmissible in the new Latin, and should invariably be rendered by *-um*.

In accordance with such rules, *Rhinoceros* has been turned into *Rhinocerus*, and *Rhinocerotidæ* into *Rhinoceridæ*. But *Rhinoceros* was admitted into classical Latinity, and with it the corresponding oblique cases, *Rhinocerotis*, etc.: in fact, the word was current in the language of description, satire, and proverb—as when used by Juvenal for a vessel made of the horn, or by Lucilius for a long-nosed man, or by Martial in the proverbial expression, "Nasum rhinocerotis habere;" i. e., to turn the nose up, as we would say. These authorities are good enough for me.

The termination *-on* was also familiar to the Romans of classic times, and numerous words with that ending may be found in the books of Pliny. But our modern purists will have none of them; the Greek *-on* in the new Latin must always become *-um*. For example, *Ophidion* was the name given to a small conger-like eel, according to Pliny, and was (without reason) supposed to have been applied to the genus now called *Ophidium;* and this last form was given by Linnæus, who eventually[1] refused to follow Pliny in such barbaric use of Latin. But Pliny is good enough for me—at least as a Latinist.

Another rule prohibits the use of such words as *Ægir*, *Göndul*, *Moho*, *Mitu*, *Pudu*, and the like, and provides that they should have other terminations in accordance with classical usage. But why should those words be changed and surcharged with new endings? As they are, they are all uniform with classical words. *Ægir* has its justification in *vir*, *Göndul* in *consul*, *Moho* in *homo* (of which it is an accidental anagram), and *Mitu* and *Pudu* are no more cacophonous or irregular than *cornu*. I therefore see no reason why we should not accept the words criticised and corrected by some naturalists in their original form, even if we consider the question involved as grammatical rather than one of scientific convenience.

I have thus defended some of the names of our old nomenclators, and really think the rules laid down for name making were too severe. But those rules were on the whole judicious, and should not be deviated from by future nomenclators without good and substantial reason. Even if too severe, they "lean to virtue's side." On the other hand, let old names be respected in the interest of stability, even if slightly misformed.

MISAPPLIED NAMES.

While Linnæus was so exacting in his rules of nomenclature in the cases cited, in others he was extremely lax. It is due to him, directly or indirectly, that our lists of genera of vertebrate animals especially

[1] At first (in the tenth edition) Linnæus allowed *Ophidion*.

are encumbered with so many ancient names that we know were applied to very different animals by the Greeks and Romans. It is Linnæus that was directly responsible for the misuse of such generic names of mammals as *Lemur*, *Manis*, *Dasypus;* such bird names as *Trochilus*, *Coracias*, *Phaëton*, *Diomedea*, *Meleagris*, and (partly with Artedi) such fish names as *Chimæra*, *Centriscus*, *Pegasus*, *Callionymus*, *Trigla*, *Amia*, *Teuthis*, *Esox*, *Elops*, *Mormyrus*, and *Exocœtus*. These all were applied by the ancients to forms most of which are now well ascertained, and the animals to which they have been transferred have nothing in common with the original possessors of the names.

The misuse of these ancient names is in contravention of the rule adopted by the International Zoological Congress held in Moscow (1892), that "every foreign word employed as a generic or specific name should retain the meaning it has in the language from which it is taken," and of like rules of other associations. The false application by Linnæus and his followers (and he had many) was due partly to the belief that the ancient names were unidentifiable, but now there are few whose original pertinence is not known. It may be thought by some, however, that we are unduly criticising the doings of the past from the vantage ground of the present. But such is not the case, for at the commencement of his career Linnæus was taken to task for the fault indicated. Some of those criticisms were so apt that they may be advantageously repeated here.

Dillenius, of Oxford, wrote to Linnæus in August, 1737, in these terms:

We all know the nomenclature of botany to be an Augean stable, which C. Hoffmann, and even Gesner, were not able to cleanse. The task requires much reading and extensive as well as various erudition; nor is it to be given up to hasty or careless hands. You rush upon it and overturn everything. I do not object to Greek words, especially in compound names; but I think the names of the antients ought not rashly and promiscuously to be transferred to our new genera or those of the New World. The day may possibly come when the plants of Theophrastus and Dioscorides may be ascertained, and till this happens we had better leave their names as we find them. That desirable end might even now be attained if anyone would visit the countries of these old botanists and make a sufficient stay there; for the inhabitants of those regions are very retentive of names and customs, and know plants at this moment by their antient appellations, very little altered, as any person who reads Bellonius may perceive. I remember your being told by the late Mr. G. Gherard that the modern Greeks give the name of *Amanita* (ἀμανίτα) to the eatable field mushroom, and yet in *Critica Botanica* (p. 50) you suppose that word to be French. Who will ever believe the *Thya* of Theophrastus to be our *Arbor vitæ?* Why do you give the name of Cactus to the *Tuna?* Do you believe the *Tuna*, or *Melocactus* (pardon the word), and the *Arbor vitæ* were known to Theophrastus? An attentive reader of the description Theophrastus gives of his *Sida* will probably agree with me that it belongs to our *Nymphæa*, and, indeed, to the white-flowered kind. You, without any reason, give that name to the *Malvinda*, and so in various other instances concerning antient names, in which I do not, like Burmann, blame you for introducing new names, but for the bad application of

old ones. If there were in these cases any resemblance between your plants and those of the antients you might be excused, but there is not. Why do you (p. 68) derive the word *Medica* from the virtues of the plant, when Pliny (Book XVIII, chap. 16) declares it to have been brought from Media? Why do you call the *Molucca Molucella?* It does not, nor ought it, to owe that name, as is commonly thought, to the Molucca Islands, for, as Lobel informs us, the name and the plant are of Asiatic origin. Why, then, do you adopt a barbarous name and make it more barbarous? *Biscutella* is not, as you declare (p. 118), a new name, having already been used by Lobel. I am surprised that you do not give the etymology of the new names which you or others have introduced. I wish you would help me to the derivation of some that I can not trace, as *Ipomœa*, for instance. Why are you so offended with some words, which you denominate barbarous, though many of them are more harmonious than others of Greek or Latin origin?

A year later (August 28, 1738) he again wrote:

It would surely have been worth your while to visit Greece, or Asia, that you might become acquainted with, and point out to us, the plants of the antients, whose appellations you have so materially, and worse than any other person, misapplied. You ought to be very cautious in changing names and appropriating them to particular genera.

How entirely the previsions of the wise old botanist have been realized I need not explain. We now know what almost all of the names misapplied by Linnæus and his school were meant for of old; and when some more good naturalists collect names and specimens together in various parts of Greece, probably very few of the ancient names will remain unidentifiable.

The only reply that Linnæus could make to the censures of Dillenius appears in the following minutes:

With regard to unoccupied names in antient writers, which I have adopted for other well-defined genera, I learned this of you. You, moreover, long ago, pointed out to me that your own *Draba*, *Nova Pl. Genera* 122, is different from the plant so called by Dioscorides.

The retort of one sinner that his antagonist is another is no real answer.

The comments of the British committee of 1865 on this subject are very judicious and pertinent.

The use of mythological names for animals and plants is far less culpable. The use of such is no worse than that of any meaningless name. Sometimes, even, there may be conveyed an association of ideas which appeals to the imagination in a not disagreeable manner. For example, Linnæus gave the name *Andromeda*, after the Ethiopian maid whose mother's overgreat boasts of the daughter's beauty made her the victim of Poseidon's wrath. Linnæus justified his procedure by a remarkable play of fancy:

This most choice and beautiful virgin gracefully erects her long and shining neck (the peduncle), her face with its rosy lips (the corolla) far excelling the best pigment. She kneels on the ground with her feet bound (the lower part of the stem incumbent), surrounded with water,

and fixed to a rock (a projecting clod), exposed to frightful dragons (frogs and newts). She bends her sorrowful face (the flower) towards the earth, stretches up her innocent arms (the branches) toward heaven, worthy of a better place and happier fate, until the welcome Perseus (summer), after conquering the monster, draws her out of the water and renders her a fruitful mother, when she raises her head (the fruit) erect.

The relation of the old myth to the plant may be farfetched, and no other would ever be likely to notice the analogy without suggestion; but at least the conceit is harmless, if not agreeable.

The analogy that gave rise to this fanciful description, contained in the "Flora Lapponica," suggested itself to Linnæus on his Lapland journey:

The Chamædaphne of Buxbaum was at this time in its highest beauty, decorating the marshy grounds in a most agreeable manner. The flowers are quite blood red before they expand, but when full grown the corolla is of flesh color. Scarcely any painter's art can so happily imitate the beauty of a fine female complexion; still less could any artificial color upon the face itself bear comparison with this lovely blossom. As I contemplated it, I could not help thinking of Andromeda as described by the poets; and the more I meditated upon their descriptions, the more applicable they seemed to the little plant before me: so that, if these writers had had it in view, they could scarcely have contrived a more apposite fable. Andromeda is represented by them as a virgin of most exquisite and unrivalled charms; but these charms remain in perfection only so long as she retains her virgin purity, which is also applicable to the plant, now preparing to celebrate its nuptials. This plant is always fixed on some little turfy hillock in the midst of the swamps, as Andromeda herself was chained to a rock in the sea, which bathed her feet, as the fresh water does the roots of the plant. Dragons and venomous serpents surrounded her, as toads and other reptiles frequent the abode of her vegetable prototype, and, when they pair in the spring, throw mud and water over its leaves and branches. As the distressed virgin cast down her blushing face through excessive affliction, so does the rosy-colored flower hang its head, growing paler and paler till it withers away. Hence, as this plant forms a new genus, I have chosen for it the name of *Andromeda*.

DOUBLE NAMES.

It was long the custom when a specific name was taken for a genus to substitute a new specific for the one so diverted. There was some reason for this, for sometimes the specific name covered several forms, or at least was equally applicable to several; of late, however, the acceptance of both the generic and specific names—that is, the duplication of a name—has been quite general, and various precedents have been adduced in favor of the procedure. "In the solemn anthem musicians have been known to favor such repetitions, the orator uses them, in poetry they occur without offense, and even our English aristocracy sometimes bears them as an added grace."[1] It is also a frequent custom in many barbarous and half-civilized races, as well as the young of

[1] Stebbing in Nat. Science, viii, 255.

our own, to double the name for a given subject; and this analogy may be regarded by some of you as a perfect one. But in the last cases some regard is had for euphony, and it is a short word that is repeated, as in the case of the Kiwi-Kiwi and Roa-Roa of the Maoris of New Zealand, the Pega-Pega of the indigenes of Cuba, the Willie-Willie (waterspout) of the Australians, and our own familiar Pa-pa and Ma-ma. Many scientific names repeated are long—some very long—but even for such I would now yield the point. Stability of nomenclature is a greater desideratum than euphony or elegance. But here let me add that there is a history behind the *Scomber Scomber*, which has been frequently cited as an example of the duplication of a name by Linnæus. It was *Scomber Scombrus* that was used at first by the early nomenclator, and that occurs in the tenth edition of the "Systema Naturæ" (p. 297), as well as in the "Fauna Suecica" (2d ed., p. 119). Linnæus thus combined the old Latin and Greek names of the mackerel, which were formally different, although of course traceable to one and the same root. The name is therefore not repulsive, but interesting as an historical reminiscence of past usage by two great peoples. It was only in the twelfth edition of the "Systema" (p. 492) that Linnæus exactly duplicated the name as *Scomber Scomber*, and thus vitiated the last edition in this as he did in other cases. But it is at least possible that the exact duplication of names in the twelfth edition is the offspring of typographical inaccuracy or clerical inadvertence.[1] At any rate, those who recognize the tenth edition of the "Systema" as the *initium* of nomenclature will adopt the more elegant form.

VARIANTS AND SIMILARITY OF NAMES.

The case of *Scomber* and *Scombrus* naturally suggest consideration of another rule adopted by various societies. By the German Zoological Society it is provided that "names of the same origin, and only differing from each other in the way they are written, are to be considered identical."[2] Words considered identical are *Fischeria* and *Fisheria*, as

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[1] In the last part of the Proceedings of the Zoological Society of London (1896, II), received September 5, the suggestion that *Scomber Scomber* was a lapsus is confirmed. According to Dr. Sclater, "on referring to the two copies of the twelfth edition, formerly belonging to Linnæus himself, and now in the library of the Linnæan Society, it will be found that the second *Scomber* is altered, apparently in Linnæus' own handwriting, into *Scombrus*. (See note on this subject, 'Ibis,' 1895, p. 168.)" P. Z. S., 1896, 310, 311.

[2] "Etymologisch gleich abgeleitete und nur in der Schreibweise von einander abweichende Namen gelten als gleich.

Beispiele: *silvestris* = *sylvestris*; *cæruleus* = *cœruleus*; *linnæi* = *linnei*; *Fischeria* = *Fisheria*; *Astracanthus* = *Asteracanthus*.

a. Dagegen können neben einander verwendet werden *Picus* und *Pica*; *Polyodon*, *Polyodonta*, und *Polyodontes*; *fluvialis*, *fluviatilis*, *fluviaticus*, *fluviorum*; *moluccensis* und *moluccanus*.

b. Bei Neubildung von Namen möge man solche vermeiden, welche leicht mit schon vorhandenen verwechselt werden können." Regeln * * * von der Deutsch. zool. Ges., § 4.

well as *Astracanthus* and *Asteracanthus;* and among words sufficiently different are *Polyodon*, *Polyodonta*, and *Polyodontes.*

When rules are once relaxed in this indefinite manner the way is at once open to differences of opinion as to what are to be considered identical or too much alike. *Fischeria* and *Fisheria* appear to me to be sufficiently distinct, and would be so considered by some who think that *Polyodon*, *Polyodonta*, and *Polyodontes* are too nearly alike. While the last three are conceded to be sufficiently distinct by the German Zoological Society, analogous forms, as *Heterodon* and *Heterodontus*, are claimed by some zoologists to be too similar, and consequently the latter prior and distinctive name of the "Port Jackson shark" is sacrificed in favor of the later and inapt *Cestracion*—a name originally coined and appropriate for the hammer-headed sharks, but misapplied to the Australian shark.

I agree with those who think that even a difference of a single letter in most cases is sufficient to entitle two or more generic names so differing to stand. The chemist has found such a difference not only ample but most convenient to designate the valency of different compounds, as ferr*i*cyanogen and ferr*o*cyanogen. I am prepared now to go back on myself in this respect. In 1831 Prince Max of Nieuwied named a bird *Scaphorhynchus*, and in 1835 Heckel gave the name *Scaphirhynchus* to a fish genus.[1] In 1863 I used a new name (*Scaphirhynchops*) for the acipenseroid genus, and that name was adopted by other naturalists. Jordan later considered the literal differences between the avine and piscine generic names to be sufficient for both. I yield the point, and abandon my name *Scaphirhynchops.* But those who hold to the rule in question will retain it.

Another set of cases exhibiting diversity of opinion may be exemplified.

In 1832 Reinhardt gave the name *Triglops* to one cottoid genus, and in 1851 Girard named another *Triglopsis*, Girard apparently not knowing of Reinhardt's genus. In 1860 the later name was replaced by *Ptyonotus.* All American naturalists have repudiated the last name.

In 1854 Girard named a genus of Atherinids *Atherinopsis*, and in 1876 Steindachner, knowing well the name of Girard, deliberately called a related genus *Atherinops.* No one, as yet, has questioned the availability of the later name, but one who refuses to adopt *Triglopsis* because of the earlier *Triglops* must substitute another name for *Atherinops.*

Who shall decide in such cases, and what shall be the standard?

[1] In lieu of explanations of the etymology, it may be assumed that *Scaphirhynchus* was derived from σκαφειά, a digging or hoeing, and that *Scaphorhynchus* is from σκάφος, anything hollowed, as a boat. Both *Scaphorhynchus* and *Scaphirhynchus* were derived from 'σκάφη, scapha; ῥυγχος, rostrum' by Agassiz in his Nomenclator Zoologicus, but the characters of the respective genera would be better expressed by the etymologies here suggested, the bird genus having a bill like an inverted boat and the fish genus a snout like a spade, as the popular name—shovel-billed sturgeon—implies.

MAKING OF NAMES.

It was long ago recognized, even by Linnæus, that the rigor of the rules originally formulated by him would have to be relaxed. Naturalists early began to complain that the Greek and Latin languages were almost or quite exhausted as sources for new names, and many resorted to other languages, framed anagrams of existent ones, or even played for a jingle of letters.

Forty years ago one of the most liberal of the American contributors to such names[1] defiantly avowed that "most of the genera [proposed by him] have been designated by words taken from the North American Indians, as being more euphonic than any one [he] might have framed from the Greek. The classic literature has already furnished so many names that there are but few instances in which a name might yet be coined and express what it is intended to represent. [He offered] this remark as a mere statement, not as an apology." He gave such names as *Minomus*, *Acomus*, *Dionda*, *Algoma*, *Algansea*, *Agosia*, *Nocomis*, *Meda*, *Cliola*, *Codoma*, *Moniana*, *Tiaroga*, *Tigoma*, *Cheonda*, and *Siboma*.

The names have caused some trouble, and have been supposed to be original offspring of the ichthyologist; but those familiar with Longfellow's Hiawatha will recognize in *Nocomis* the name of the daughter of the Moon[2] and mother of Wenonah[3] (Nokomis), corrected by classical standard! and in *Meda* the title of a "medicine man" (not "a classical feminine name"). Other names are geographical or individual.

In the excellent report to the International Zoological Congress, by Dr. Raphael Blanchard (1889), it was remarked that it would be generally conceded that naturalists have almost completely exhausted the Greek and Latin words, simple and compound, possible to attribute to animals.[4]

But the classic languages are even yet, although about one hundred thousand names[5] grace or cumber the nomenclators, far from being completely exploited. To some of us, indeed, the difficulty in determining upon a new name is that of selection of several that are conjured up by the imagination rather than the coining of a single one.

Besides the methods of name-making generally resorted to, there are others that have been little employed. Among the few who have resorted to other than the regular conventional ways is the illustrious

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[1] Girard in Proc. Acad. Nat. Sc. Phila., viii., 209, 1856.

[2] "From the full moon fell Nokomis,
Fell the beautiful Nokomis."
The song of Hiawatha, III., lines 4, 5.

[3] Ophiologists will recognize in Wenonah the source of a synonym (*Wenona*) given to the genus *Charina* by Baird and Girard. Oct., 1896.

[4] "On conviendra que les naturalistes ont dû épuiser à peu près complètement la liste des mots grecs ou latins, simple ou composés, qu'il était possible d'attribuer aux animaux." Bul. Soc. Zool. France, XIV., 223.

[5] The number one hundred thousand includes duplicates and variants.

actual president of the American Association for the Advancement of Science.[1] His long list of generic names proposed in the various departments of zoology embraces many of unusual origin, and almost always well formed, elegant, and euphonious. I can only adduce a few of the ways of naming illustrated by classical examples.

In ancient Greek there are numerous words ending in *-ias*, and many substantives with that termination are names of animals given in allusion to some special characteristic.

Acanthias is the designation of a shark, especially distinguished by the development of a spine at the front of each dorsal fin; the name is derived from *ἄκανθα*, spine, and the terminal element.

Acontias is the name of "a quick-darting serpent," and the main component is *ἄκων*, a dart or javelin.

Anthias is the name of a fish found in the Mediterranean and distinguished by the brilliancy of its color; evidently it was based on *ἄνθος*, a flower. The color of the fish may remind one of a showy flower.[2]

Xiphias is the ancient as well as zoological designation of the swordfish; it was plainly coined from *ξίφος*, a sword.

These four names give some idea of the range of utility of the particle in question; they involve the ideas of defensive armature, offensive armature, ornamentation, and action.

A number of names have been framed by modern zoologists in conformity with such models. Such are *Stomias* (named by the Greek scholar and naturalist, Schneider) and *Ceratias*—types of the families *Stomiidæ* (generally written *Stomiatidæ*) and *Ceratiidæ*. *Tamias* is another name, well known in connection with the chipmunk.

But there is room for many more of like structure. For example, peculiarities of various parts might be hinted at by such words as *Carias* or *Cephalias* or *Cotidias* or *Cottias* (for animals having some distinctive character in the head), *Chirias* (hand or hand-like organ), *Gnathias* (jaw), *Podias* (feet), *Thoracias* (thorax), and many others of analogous import.

Another termination which might be used advantageously instead of the too-often used *-oides* is the patronymic suffix *-ides*. This would be especially useful where genetic relationship is desired to be indicated. We have many such models in classical literature, as Alcides, the son of Alcæus; Atrides, the son of Atreus; Pelides, the son of Peleus; Æacides, the grandson of Æacus, and the like.

Another source for help in name-making is in the several intensive Greek particles occurring as prefixes of various names. The chief of these prefixes are *agi-*, *ari-*, *da-*, *eri-*, *eu-*, and *za-*. *Eu-* has been so very often drafted into use that relief and variety may be found by resorting to the others.

[1] Prof. E. D. Cope.

[2] Thoreau calls trout "these bright fluviatile flowers." Maine Woods, 1864, 54.

Ari- (Ἀρι-) occurs often in classical words, as ἀρίδακρυς (very tearful), ἀρίδηλος (very plain), and ἀριπρεπής (very showy).

Da- (Δα-) is illustrated by such names as δάσκιος (daskios, shaded) and δαφοινός (daphoinos, deep red); convert them, if you will, into *Dascius* and *Daphœnus*. Numerous names may be made on the model, although in classical Greek there are few.

Eri- (Ἐρι-) is used in the same way as *Ari-*, and is familiar in ancient Greek as a particle of such words as ἐριαυγής (very brilliant) and ἐριαύχην (with a high arched neck). The common large seal of northern Europe (*Erignathus barbatus*) has received its generic name, based on the same model, on account of the depth of the jaws. Very few naturalists, however, have availed themselves of this particle for name-making, most of the words in the zoological nomenclature commencing with *Eri-* having other origins.

Za- (Ζα-) is met with in such words as ζαής (strong blowing), ζαθερής (very hot), ζακαλλής (very beautiful), ζάπλουτος (very rich), ζαπότης (a hard drinker). The particle has been utilized in the composition of the generic name (*Zalophus*) of the common sea lion, distinguished by its high sagittal crest (ζα- and λόφος, crest), familiar to menagerie visitors and the residents and travelers in San Francisco. Professor Cope has also made use of it for several of his names.

We have been told by ancient writers that Cicero was a name derived from *cicer*, a vetch. According to Pliny, the name (like *Fabius* and *Lentulus*) was obtained on account of ancestral skill in cultivation of the plant; but, according to Plutarch, the original of the name was so called because he had a vetch-like wen on his nose.[1] Which one (if either) was the fact is of no material consequence. The etymological propriety of both is sanctioned by the suppositions of classical writers. There can, then, be no valid objection to other names formed on the model.

There is one rule which has been put in such a form (and without proper exceptions) that a number of names, improper according to classical standards, have been introduced. The rule is that the aspirate of Greek should be rendered by *h*. While this is true for the commencement of a name, it is not for the body, where it generally is suppressed, being sonant only after *p*, *t*, or *k*. The Greeks, accordingly, wrote *Philippos* (Φίλιππος) and *Ephippus* (Ἔφιππος). In accordance with such models *Mesohippus* and *Orohippus* should have been called *Mesippus* and *Orippus*. *Protohippus* should have been *Prothippus*. *Epihippus* might by some be considered to be preoccupied by *Ephippus*, a genus of fishes. But, in my opinion, all the names should be retained as they are (if there is no other objection), on the assumption that

[1] Those familiar with the 'Spectator' may recall Addison's allusion to this (No. 59) See also Middleton's Life of Cicero.

more confusion would result from sacrifice of priority than of classical excellence.

From names as names I proceed to the consideration of fitting them to groups.

TYPONYMS.

The question, What is necessary to insure reception of a generic name? is one of those concerning which there is difference of opinion. By some a definition is considered to be requisite, while by others the specification of a type is only required. But the demand in such case is simply that the definition shall be made. It may be inaccurate or not to the point; it may be given up at once, and never adopted by the author himself afterwards, or by anyone else. Nevertheless, the condition is fulfilled by the attempt to give the definition. In short, the attempt is required in order that the competency (or its want) of the namer may be known, and if incompetency is shown thereby, no matter; the attempt has been made. The indication by a type is not sufficient!

Anyone who has had occasion to investigate the history of some large group must have been often perplexed in determining on what special subdivision of a disintegrated genus the original name should be settled. The old genus may have been a very comprehensive one, covering many genera and even families of modern zoology, and of course the investigator has to ignore the original diagnosis. He must often acknowledge how much better it would have been if the genus had been originally indicated by a type rather than a diagnosis. Many naturalists, therefore, now recognize a typonym to be eligible as a generic name. Among such are those guided by the code formulated by the American Ornithologists' Union, to which reference may be made, and in which will be found some judicious remarks on the subject under Canon XLII. Certainly it is more rational to accept a typonym than to require a definition for show rather than use. Nevertheless, I fully recognize the obligation of the genus-maker to indicate by diagnosis as well as type his conception of generic characters.

FIRST SPECIES OF A GENUS NOT ITS TYPE.

On account of the difficulty of determining the applicability of a generic name when a large genus is to be subdivided, it has been the practice of some zoologists to take the first species of a genus as its type. This, it has been claimed, is in pursuance of the law of priority. It is, however, an extreme, if not illegitimate, extension of the law, and has generally been discarded in recent years. But in the past it had eminent advocates, such as George Robert Gray in ornithology and Pieter van Bleeker in ichthyology. A few still adhere to the practice, and within a few months two excellent zoologists have defended their

application of names by statements that the first species of the old genera justified their procedure. The contention of one involves the names which shall be given to the crayfishes and lobsters.

It is evident that the fathers of zoological nomenclature never contemplated such a treatment of their names, and the application of the rule to their genera would result in some curious and unexpected conditions. Let us see how some genera of Linnæus would fare. The first species of *Phoca* was the fur seal; the first species of *Mustela*, the sea otter; the first of *Mus*, the guinea pig, and the first of *Cervus* was the giraffe. These are sufficient to show what incongruities would flow from the adoption of the rule.

CHOICE OF NAMES SIMULTANEOUSLY PUBLISHED.

There is another issue of nomenclature involving many genera. In the same work different names have been given to representatives or stages of what are now considered the same genus. For example, Lacépède, in the third volume of his "Histoire Naturelle des Poissons," published two names, *Cephalacanthus* and *Dactylopterus*, the former given to the young and the latter to the adult stage of the flying gurnard. *Cephalacanthus* appeared on page 323, and *Dactylopterus* on page 325. *Dactylopterus* is the name that has been generally adopted for the genus, but some excellent naturalists now insist on the resurrection and retention of *Cephalacanthus*, for the reason that the latter was the first given name. In connection with an analogous case, it was urged that "the law of primogeniture applies to twins." There is a fallacy involved in such a comparison, which becomes obvious enough on consideration. In the case of twins, the birth of one precedes that of the other by a very appreciable interval of time. But in the case of names appearing in the same volume (issued as a whole) the publication is necessarily simultaneous. It is therefore, it appears to me, perfectly logical to take the most appropriate name, or to follow the zoologist who first selected one of the names. In the case of *Dactylopterus* there would be the further advantage that the current nomenclature would not be disturbed.

It is interesting to note that those who have acted on the principle just condemned do not feel called upon to accept the first species of a genus as its type.

MAJOR GROUPS AND THEIR NOMENCLATURE.

Another subject to which I would invite your attention is the amount of subdivision of the animal kingdom which is expedient, and the nomenclature of such subdivisions.

Linnæus only admitted four categories—class, order, genus, and species. These sufficed for most naturalists during the entire past century. Only one naturalist—Gottlieb Conrad Christian Storr—went

into much greater detail; he admitted as many as eleven categories, which may be roughly compared with modern groups as follows:

Agmen	Rubrisanguia [=Vertebrata]	Subkingdom
Acies	Warm-blooded Cold-blooded	Superclass
Class	Mammalia	Class
Phalanx	Pedata Pinnepedia Pinnata	Subclass
Cohors	Unguiculata Ungulata	Superorder
Ordo		Order
Missus		Suborder
Sectio		Family
Coetus		Subfamily
Genus		Genus
Species		Species

These groups are not exactly comparable with any of recent systematists, inasmuch as Storr proceeded from a physiological instead of a morphological base in his classification. The only work in which this classification was exhibited was in his "Prodromus Methodi Mammalium," published in 1780.

With this exception the naturalists of the last century *practically* recognized only four categories—species, genera, orders, and classes. Families were introduced into the system by Latreille. The word "family," it is true, was not unknown previously, but it had been used only as a synonym for order. In botany such usage even prevails to some extent at the present day, and persists as a heritage of the past. The French botanists used "famille" as the equivalent of "ordo." Our English and American botanists followed and used "order" as the more scientific designation and "family" as a popular one; Gray, for example, calling the family represented by the buttercups the "Order Ranunculaceæ," or "Crowfoot Family." But in zoology the two names became early differentiated, and while order was continued in use with the approximate limits assigned to it by Linnæus, family was interposed as a new category, intermediate between the order and genus. At first this category generally was given a descriptive designation, but soon the tendency to employ as a part of the designation the stem of the principal generic name became marked, and the use of the patronymic suffix *-idæ* in connection with a generic name was adopted, and as time has advanced has become more and more general. But the assent to this method is not universal. There are still some excellent zoologists who refuse to be bound by the rule and who adopt the oldest family name, whether it be denominative or patronymic and whatever may be the termination.

The five categories thus recognized were very generally admitted, and for a long time were the only ones recognized by many naturalists.

But gradually suborders, subfamilies, and subgenera were taken up. Further, the word "tribe" was often used, but with different applications. Still other divisions were occasionally introduced, but the most elaborate of all the schemes for gradation of the groups of the animal kingdom were those proposed by Bleeker[1] and Haeckel.[2] They are reproduced in the following parallel columns, in which their applications to fishes and mammals are likewise shown:

Vertebrata	Phylum		
Pachycardia	Subphylum		
Allantoidia	Cladus		
	Subcladus		
Mammalia	CLASSIS	CLASSIS	*Pisces*
Monodelphia	Subclassis	Subclassis	*Monopnoi*
		Divisio	*Dirhinichthyes*
Deciduata	Legio	Legio	*Eleutherognathi*
Discoplacentalia	Sublegio	Sublegio	*Ctenobranchii*
		Series	*Isopleuri*
		Subseries	*Kanonikodermi*
		Phalanx	*Alethinichthyes*
		Subphalanx	*Neopoiesichthyes*
		Caterva	*Katapieseocephali*
Rodentia	ORDO	ORDO	*Percæ*
	Subordo	Subordo	*Percichthyini* [sic!]
Myomorpha	Sectio	Sectio	*Paristemipteri*
	Subsectio		
		Tribus	*Percichthyini* [sic!]
Murina	FAMILIA	FAMILIA	*Percoidei*
	Subfamilia	Subfamilia	*Percæformes*
Arvicolida	*Tribus*	*Cohors*	
Hypudæi	*Subtribus*	Stirps	
Arvicola	GENUS	GENUS	*Perca*
	Subgenus		
Paludicola	*Cohors*		
	Subcohors		
Arvicola amphibius	SPECIES	SPECIES	*Perca fluviatilis*
	Subspecies		
Arvicola (amphibius) terrestris	Varietas		
Arvicola (amphibius terrestris) argentoratensis	Subvarietas		

Here we have a total of 31 categories intermediate between the kingdom and the individual of an animal form. The tools have become too numerous, and some were rarely used by the authors themselves. Thus the cohors and stirps were not called into requisition by Bleeker for the Percoidei (though they were for the subdivision of the Cyprinoidei), and in the recent classification of the Radiolarians Professor Haeckel

[1] Enumeratio specierum Piscium hucusque in Archipelago Indico observatorum, p. xi et seq., 1859.

[2] Generelle Morphologie der Organismen, II, 400, 1866.

did not find it necessary to draw upon the tribus or subtribus for the arrangement of any family. None others have adopted in detail either of the elaborate schemes proposed by their distinguished authors, and even those authors themselves have not, in their later works, gone into the details they provided for in their schemes. The only divisional name that has been used to any great extent is tribe. That has been frequently employed, but in different ways—sometimes for the division of an order, sometimes within a suborder, sometimes for a section of a family, again for a part of a subfamily, and even for a fragment of a genus.[1] In two of these widely differing ways it has been used in the systems of Bleeker and Haeckel. It is evident, however, that more groups than the old conventional ones, which alone Agassiz admitted, would be useful at present. A happy mean seems to be realized in the following list:

Branch	Superfamily
Subbranch	Family
Superclass	Subfamily
Class	Supergenus
Subclass	Genus
Superorder	Subgenus
Order	Species
Suborder	Subspecies

There are only two (or three for trinomialists) of these which are "sonant," all the others being "mute" (to use the expression of Linnæus); but a question of termination affects several of them.

All the supergeneric groups, like families, were originally chiefly designated by descriptive names, but the trend in all the years has been toward names which are based on the stems of existing genera.

FAMILY.

In 1796–97 ("an 5 de la R."), Latreille, in his "Précis des Caractères génériques des Insectes," for the first time employed the term "family" as a subdivision of an order, but only gave the families numbers ("Famille première," "Fam. 2," etc.).[2] He remarked that it might be desirable to have the families named, but deferred doing so till he could review the subject with greater care.[3]

In 1798 ("an 6"), Cuvier, in his "Tableau Élémentaire de l'Histoire naturelle des Animaux," in the introduction, when treating of graded

[1] The words "phalanx," "cohors," and "series" (if not others) have been used recently in another manner by Dr. F. A. Smitt in the "History of Scandinavian Fishes." The sequence in that work is Classis, Ordo, Subordo, Phalanx, Cohors, Series, Familia, Subfamilia, Genus, Subgenus, Species.

[2] "Les rapports anatomique, ceux de *l'Habitus*, des métamorphoses, ont été mes guides dans la formation des familles. Elles sont précédées d'un chiffre arabe." p. ix.

[3] On eut désiré que j'eusse donné des noms aux familles; mais prévoyant que je serois contraint d'y faire plusieurs changemens, j'eusse ainsi exposé la nomenclature à une vicissitude très contraire à l'avancement de la science." p. ix.

characters (*"caractères gradués"*), named only the genus, order, class, and the kingdom. In the body of the work sometimes he used the word family instead of order (as for the Birds), but for two orders of the Insects he formally adopted a division into families which were regularly named. The first (unnamed) order ("ordre"), with jaws and without wings ("Des insectes pourvus de mâchoires, et sans ailes"), was divided into several families ("plusieurs familles naturelles")—"les Crustacés," "les Millepieds," "les Aracnéides," and "les Phtyréides." The order Névroptères was disintegrated into three families ("trois familles naturelles")—"les Libelles," "les Perles," and "les Agnathes." The representatives of the other (six) orders were distributed directly into genera.

This, so far as I have been able to discover, was the first time in which an order of the animal kingdom was regularly divided into named families, designated as such.

In 1806 Latreille, in his "Genera Crustaceorum et Insectorum," gave names to families, but on no uniform plan, providing descriptive names for some, as "*Oxyrhinci*" for the Maioidean crabs, names based on typical genera, with a patronymic termination, as *Palinurini* and *Astacini*, and in other cases names also based on a typical genus, but with a quasi-plural form, as *Pagurii*. (In the same work, it may be well to add, Latreille also admitted more categories than usual, using ten for the animal kingdom—Sectio, Classis, Legio, Centuria, Cohors, Ordo, Familia, Tribus, Genus, and Species.)

In 1806 A. M. Constant Duméril, who had previously contributed tables of classification to Cuvier's "Leçons d'Anatomie Comparée," and published his own "Elemens d'Histoire Naturelle," brought out his "Zoologie Analytique." In this volume he gave analytical tables for the entire animal kingdom and admitted families for all the classes. The families were generally subordinated to orders, but when the structural diversity within a class did not appear sufficient to require more than one "mute" category the order was sacrificed in favor of the family. His families were generally very comprehensive, often very unnatural, and mostly endowed with descriptive names. (He admitted no more than five named categories in the animal kingdom—class, order, family, genus, and species.)

As we have seen, Cuvier, Latreille, Rafinesque, and others to some extent, used names ending in *-ides* and *-ini*, but the first to fully recognize the advisability of using patronymic family names universally was William Kirby, who has not often received the credit for so doing, and is probably unknown to most in such connection. Nevertheless, in a note to his memoir on "Strepsiptera, a new order of insects proposed,"[1] he explicitly introduced this important feature in systematic

[1] The suggestion of Kirby is to be found in a footnote (p. 88) to the seventh memoir published in "The Transactions of the Linnæan Society of London" (XI., 86–122, pl. 8, 9). The memoir was "read March 19, 1811." The date of the whole volume is 1815.

terminology. He complained that Latreille's names "have not that harmony and uniformity of termination which is necessary to make them easily retained by the memory." Continuing he added, "If we adopted a patronymic appellation for these sections, for instance, Coleoptera *Scarabæidæ*, Coleoptera *Staphylinidæ*, Coleoptera *Sphæridiadæ*, Orthoptera *Gryllidæ*, etc., it would be liable to no objection of this kind."

The suggestion thus made was heeded. The English naturalists (especially William Elford Leach and John Edward Gray) soon applied the method inculcated, and from them it has spread to the naturalists of every land, but the original impulse has been forgotten. For this reason I have recalled the memory of Kirby's work.

But it was long before the expediency of this procedure was universally recognized, and even yet there are dissentients. One objection was that the termination *-idæ* was not consistent with Latin words. Prof. Agassiz was never reconciled to such names, and gave names of Greek origin the termination *-oidæ*, and those of Latin the ending *-inæ*. In his system, too, there was no distinction between families and subfamilies, both having terminations in consonance with the origin of the stems, and not the taxonomic value of the groups.

The endings *-idæ* and *-oidæ* have been often supposed to be identical, and even in highly esteemed dictionaries (as "The Imperial Dictionary of the English Language") the terminal element of family names ending in *-idæ* is derived from "εἶδος, resemblance." As already indicated, however, words so terminated should be considered as patronymics. But those ending in *-oidæ*, *-oidei*, and *-oidea* may be assumed to be direct components with εἶδος.

In answer to the objection (by Burmeister, for example) that patronymic names are foreign to the genius of the Latin language, or at least of Latin prose, the fact that such a poet as Virgil has a large number, shows that there is no prevailing antagonism.

SUBFAMILY.

Next to the family, the term "subfamily" was the earliest, and has been the one most generally accepted of the groups now adopted. But the name itself was not used till long after "family" had come into general vogue. The chief subdivision of the family had been named tribe ("*tribu*"), by Latreille, in 1806, and he continued to use that term. C. S. Rafinesque, in 1815, used the word subfamily ("*sous-famille*") for groups of the same relative rank as the "tribu" of Latreille, but gave generally descriptive names, with modified nominative plural endings (*e. g.*, *Monodactylia*), although sometimes he named the group after the principal genus (*e. g.*, *Percidia*). The subfamily is now generally recognized, and its ending rendered by *-inæ*, or more seldom *-ini* or *-ina*. This is rather a termination for Latin adjectives involving the idea of relation or pertinence.

But, as has been already urged, the language of nomenclature should not be bound by rules of strict philology. One of the most useful devices of scientific terminology is the establishment of terminations which indicate the nature or value of a group, or relation to the group to which some entity belongs.

The chemist has his terminations in *-ates*, *-ides*, and *-gens*, and does not deem it incumbent to defend his usage or to abandon his system because some one might object to the want of classical models. Nay, classical scholars themselves have recognized the legitimacy and usefulness of such a method.

The ending *-idæ* has been shown to have classical sanction for both Greek and Latin: *-inæ* has only classical sanction for Latin words, and there is one, *-oidea*, for which no models are to be found in either language. But the convenience of all those endings, as indicative at once of the taxonomic value of each group, far outweighs any objection to them from the philological side. We are now confronted with the groups having the *-oidea* ending.

SUPERFAMILY.

Experience has shown that for the exhibition of difference in value of various groups and characters, more than the generally accepted groups—families and subfamilies—are desirable. Groups above the family, in the generality of their characters, had been frequently adopted. A quarter century ago I searched for an available name and notation for such a group, and found that the groups which I wished to recognize were most like those that Dana had recognized in the Crustaceans, under the name of subtribe, and given the ending *-oidea*. But the term "tribe" had first been given and most generally used for a subdivision of the family, and consequently was ineligible for a group including a family. Other names had been given to such groups, but there were objections against them. In a communication to the American Association for the Advancement of Science (Volume XX) I used a new name—superfamily—and the termination *-oidea*. The great advantage of the name was that it relieved the memory, and suggested at once what was meant by relation to a familiar standard—family. The term has been quite generally adopted, but there has been diversity of usage in the form of the names, *-oideæ* being frequently suffixed to the stem, and sometimes a descriptive name has been given. The only reason for the ending *-oidea* is that it was first used in such connection; *-oideæ* has the advantage (or disadvantage?) that it is in consonance with *-idæ* and *-inæ*. No provision has been made by the German Zoological Society for this category, their attention having been confined to family and subfamily nomenclature.[1]

[1] "Die Namen von Familien und Unterfamilien werden fortan von dem gültigen Namen einer zu diesen Gruppen gehörigen Gattung gebildet, und zwar die der Familien durch Anhängen der Endung *idæ* (Plural von *ides* [gr. εἴδης] masc. gen.), die der Unterfamilien durch Anhängen der Endung *inæ* (fem. gen.) an den Stamm des betreffenden Gattungsnamens." Regeln . . . von der Deutsch. Zool. Ges., § 28.

OTHER GROUPS.

Time does not permit of the consideration of the other groups—order, suborder, class, subclass, superclass, branch, etc. Nevertheless a caveat is in order that there appears to be no reason why the principle of priority now so generally recognized for the subordinate groups should not prevail for the higher. Why should the name Amphibia disappear and Batrachia and Reptilia usurp its place? Amphibia is a far better name for the Batrachia and in every way defensible for it. The name had especial relation to it originally, and it was first restricted to it as a class. Why should the names Sauria and Serpentes give place to Lacertilia and Ophidia? The first are names familiar to all, and correctly formed; the last are, at least, strangely framed. Why should not Meantia be adopted as an ordinal name by those who regard the Sirenids as representatives of a distinct order, as did Linnæus? Why should not the ordinal names Bruta, Feræ, Glires, and Cete prevail over Edentata, Carnivora, Rodentia, and Cetacea? If the rules formulated by the various societies are applied to those groups, the earliest names must be revived.

COMPLAINTS OF INSTABILITY OF NOMENCLATURE.

Frequent are the laments over the instability of our systematic nomenclature; bitter the complaints against those who change names. But surely such complaints are unjust when urged against those who range themselves under laws. We are forcibly reminded by such complaints of the ancient apologue of the wolf and the lamb. The stream of nomenclature has indeed been much muddied, but it is due to the acts of those who refuse to be bound by laws or reason. The only way to purify the stream is to clear out all the disturbing elements. In doing so mud that has settled for a time may be disturbed, but this is at worst anticipating what would have inevitably happened sooner or later. We are suffering from the ignorance or misdeeds of the past. In opposing the necessary rectifications and the enforcement of the laws, extremes may meet; conservatives and anarchists agree. But the majority may be depended upon in time to subscribe to the laws, and the perturbed condition will then cease to be.

It is unfortunate that our nomenclature should have been so wedded to systematic zoology, and devised to express the different phases of our knowledge or understanding of morphological facts. Even under the binomial system the disturbing element might have been made much less than it is. The genera of Linnæus recognized for the animal kingdom were generally very comprehensive; sometimes, as in the case of *Petromyzon*, *Asterias*, and *Echinus*, answering to a modern class; sometimes, like *Testudo*, *Rana*, *Cancer*, *Scorpio*, *Aranea*, *Scolopendra*, and *Julus*, to a modern order, or even more comprehensive group, and rarely, among Vertebrates, to a group of less than family value. The usage of

Linnæus for the animal kingdom was very different from that for the vegetable kingdom. If the successors of Linnæus had been content to take genera of like high rank (equivalent to families, for example), and give other names to the subdivisions (or subgenera) of such genera, which, to use the language of Linnæus, should be mute, less change would have subsequently resulted. But (Linnæus himself leading) his successors successively divided a genus, gradually accepting a lower and lower standard of value, till now a genus is little more than a multiform or very distinct isolated species. Yet the change has been very gradual. It began by taking a comprehensive group, recognizing that the differences between its representatives were greater than those existing between certain genera already established, and therefore the old genus was split up; or it was perceived that the characters used to define a genus were of less systematic importance than others found within the limits of the old genus, and, to bring into prominence such a truth, the genus was disintegrated. The process often repeated, and from successively contracted bases, has led to the present condition.

The existing system of restricted genera, however, is too firmly fixed to revert back to a method that might have been, and which indeed Cuvier attempted to introduce by his revised Linnæan genera and their subgenera. The best thing to do now is to accept the current system, purified as much as possible by judicious and inexorably applied laws. Doubtless in the distant future a less cumbrous and changeable system of notation will be devised, but in the meantime we had best put up with the present, inconvenient though it be.

THE WAR WITH THE MICROBES.[1]

By E. A. de Schweinitz.

From the moment that man made his appearance in the world there has been perpetual warfare between himself and everything animate and inanimate upon the earth. To a great extent this has been an aggressive strife, man's every effort being exerted to compel nature to contribute to his comfort, welfare, and advancement by the subjugation of her materials and forces. It was many centuries, however, before he recognized that there were certain unknown insidious enemies, which often rendered fruitless his simple household occupations, defied his every effort at control, and sometimes menaced even his well-being and life. Though in 1675 Leeuwenhoeck discovered, with a powerful magnifying glass, certain minute organisms in decomposing animal matter, it was not until nearly two centuries later that their true significance was recognized, and Davaine first demonstrated the positive connection between these minute forms of life and disease. When animal and vegetable life ceased, in accordance with the laws of nature, they were supposed to be changed by purely chemical actions, so that their elements were again returned to the earth and air to supply food for other plants and animals. This destruction was considered to be wrought simply by the oxygen of the air, and the process of fermentation was thought to be due to a similar cause. It had been known for ages that the juice of the grape, if allowed to stand, underwent changes by which its character was modified and wine was formed, or this change might be allowed to progress further until the juice had been converted into vinegar and finally carbon dioxid gas and water. These alterations, those which take place in the digestive tract of animals and are involved in the conversion of dead animal and plant matter into their simplest constituents, were classed under the general head of fermentations.

The fermentations, especially that of wine, an Italian chemist, Fabroni, in 1822, supposed to be induced by a substance of vegetable origin, but closely allied to the white of egg. He considered this material identical with the gluten of cereals and gave to it the name of

[1] Address of the president before the Chemical Society of Washington, March 9, 1897. Printed in Science, Vol. V, No. 119, pages 561–570.

the "principle vegetoanimal." For nearly forty years afterwards this theory was applied by chemists to all fermentations. It was supposed that the albuminoid substance present exposed to the oxygen of the air experienced a progressively variable alteration, that diverse modifications of matter were produced which constituted the ferments of diverse nature. The fermentation was the result of the molecular movement thus communicated. These theories were based upon an erroneous interpretation of what occurred under certain conditions. There exists in wine, when it is being converted into vinegar, a substance which acts to bring about this modification, but this is not dead albuminoid matter, but a living plant. This fact the lamented chemist, Pasteur, demonstrated in his careful studies upon the production of wine and its conversion into vinegar. Before this time, it is true, there were many who failed to accept the theory of spontaneous oxidation, and endeavored to show that if fermentable liquids were boiled in flasks which were then immediately sealed, the fermentation could not take place. But this did not fulfill the demands of one school of chemists, viz, that plenty of oxygen gas should always be present. When the liquid was boiled in contact with air which had previously been drawn through sulphuric acid, it was claimed that the air had undergone some chemical change, so it was not until 1854 that this objection was overcome by previously passing the air in the presence of which boiling took place through cotton, and it was then that this school of chemists found their theories in danger. Pasteur demonstrated that the plant present in the preparation of vinegar was the simplest form of life, a cell which could be easily destroyed by heat. Its presence was absolutely necessary for fermentation, and without the living cell no amount of dead vegetable matter could cause the peculiar molecular disarrangement which had been claimed. Liebig had contended that as long as the juice of the grape remained away from contact with the oxygen of the air the necessary motion could not be imparted to the molecules, which movement subsequently caused the phenomena of fermentation. Thus was brought to an end the strife between the two schools of vitalists and chemists; the one school of chemists demanding the presence of oxygen only, the other the presence of a living plant cell in addition to oxygen. From this strife of the two schools was evolved in reality a new science and new theories, which have made the past thirty years marvelous in giving explanations of many of the simplest phenomena of plant and animal life and death, placed the practice of medicine upon a scientific basis, and rendered possible an intelligent system of agriculture and animal husbandry.

Pasteur's discoveries also served to explain the true cause of the poisonous properties of spoiled meats and other foods, stagnant water, and water from marshy countries. For more than half a century before this time a number of investigators had proved the dangerous character of old sausage, meats, bread, and the like. Kerner concluded that they contained a fatty acid to which the poisonous action was due;

others confirmed these ideas and came to similar conclusions in regard to poisonous cheese. In 1856 Panum asserted, as a result of his studies upon the poisons found in putrid animal matter, that these poisons might be formed by some active plant cell, but their injurious effect was independent of these cells. He demonstrated that fixed nonvolatile poisons could be extracted from putrid matter, which were soluble in water and alcohol, not destroyed by heat, and produced the same effects after they had been submitted to a high temperature as before. These poisons he found to be intense in their action, 0.012 gram sufficing to cause the death of a small animal. In 1866 Bence-Jones obtained from the liver a substance which, with dilute sulphuric acid, gave a bright blue fluorescence like that noted in similar solutions of quinine. Probably this was the product of what we now call fluorescing bacteria.

The work of Pasteur threw light upon the origins of these poisons. As the ferment causes the alteration in the grape juice, so do microscopic forms of life bring about the changes which take place in dead animal and vegetable matter, and also those conditions in the living body which we call disease.

Many of these microscopic forms of single-celled plants, the bacteria, have their natural habitat upon dead organic matter, but they may flourish in the living body, and are almost unlimited in variety, appearance, and behavior. It is possible also to cultivate them upon specially prepared solutions. after their individual peculiarities have been studied. Some thrive best in light, others in darkness; some like a goodly supply of oxygen, others prefer nitrogen; some are very sensitive to changes of temperature, while others readily accustom themselves to vicissitudes.

These different bacteria further are somewhat eccentric within as well as without the animal body. Some, as the diphtheria germs, find their most comfortable habitat upon certain mucous membranes, others in the lungs, some in the digestive tract, still others in the blood, while others again confine themselves to certain external cells and membranes. In their artificial cultivation this eccentricity is equally apparent. While nearly all thrive upon beef broth, some prefer the beef broth with an excess of acid, others with an excess of alkali. Some demand the addition of sugar or glycerine, others the addition of sugar together with acid, while some are satisfied with a diet of phosphates, salt, and water. These peculiarities have to be studied for each germ, and while many can accommodate themselves to their surroundings, and while the same germ grown upon different media produces the same substances, the amount of each substance is a varying one, and in cultivating them artificially we must find which diet gives rise to the largest amount of the most active products.

Shortly after the work of Panum just referred to, the Italian chemist Selmi outlined methods of extracting poisonous principles from dead animal matter, and gave to these substances the name ptomaines, on account of their origin. Later, in 1876, the first analysis of a ptomaine was made by Nencki and its formula determined. Further experiments

showed that volatile and nonvolatile substances, akaline in character, could be obtained from various portions of the animal body, often from fresh material and also from the cultures of bacteria. These ptomaines were found to resemble the alkaloids in their chemical reactions.

In 1882–83 Brieger succeeded in separating and determining a number of these ptomaines, from the brain, from fish muscarin, from decomposed glue, neuridine and dimethyl amine, etc. From pure cultures of the typhoid germ he obtained a substance, typhotoxin, which produced typhoid symptoms, and from cultures of the tetanus germ tetanin, which caused convulsions. The presence of similar poisonous bases was demonstrated in cultures of the cholera, hog cholera, anthrax, pyogenes aureus and like active bodies were isolated from cheese, milk, ice cream, sausage, and other foods which had caused sickness.

The isolation of these poisons from bacterial cultures gave rise to the belief that they were the bodies which caused the fatal effects of disease. But while in many instances they produced the characteristic symptoms, in others they were not sufficient to account for all the phenomena. For example, from cultures of the tetanus germ it was possible to isolate a base that had but slight poisonous properties, while the culture liquid from which this was obtained after all the germs had been removed was ten thousand times more poisonous than the base secured. Nonpoisonous ptomaines were also obtained from cultures of disease-producing bacteria, and, in fact, the majority of ptomaines were found to be nonpoisonous.

The next question was, If in the culture liquids freed from bacteria poisonous substances are obtained, and if they do not belong to the class of ptomaines, how shall they be identified and classified? In 1886 Mitchell and Reichert, while studying the venoms of serpents, noted that these poisons belonged to a class of bodies different from the ptomaines, viz, to the group called proteids. Shortly after, Roux and Yersin, in their studies upon the diphtheria poison, demonstrated that this was a substance which resembled the ferments and were led to think that an enzyme, as it is called, a substance like pepsin, was the active poison, and that this enzyme was in some way elaborated by the germ. Other investigators had found a similar substance in tetanus and hog cholera cultures, and a reinvestigation by Brieger of a number of bacterial cultures showed that by precipitation with ammonium sulphate and alcohol very poisonous substances giving proteid reactions could be obtained. Proteids of various characters belonging to different classes were obtained from cultures of many bacteria. About this time it was shown that certain plants of a higher order contained poisonous bodies of a like proteid character. An albumose abrin was obtained from the Jequirity seeds and ricin from the castor-oil bean. These were intensely poisonous, $\frac{1}{100000}$ of a grain of abrin being sufficient to kill an animal weighing one kilogram, or the $\frac{1}{100}$ of a grain should be a fatal dose for a man weighing about 130 pounds.

A relationship was thus established between the poisons from higher plants and from the lowest plants, and certain animals. Was this poisonous property of these bacterial substances due to a true proteid, or was there an admixture of an active, ferment-like substance with the proteid, and are these poisons mechanically carried down in the process of precipitation of the albuminoid matter in the culture liquids? Experiments show that while the poisons may be proteids, it is more than probable that they are simply carried down with proteid matter as indicated. Brieger in 1893, in view of the results so far obtained, endeavored to isolate the pure poison from cultures of the tetanus bacillus. The cultures were first filtered through porous porcelain, a Chamberland filter tube, for instance, and the liquid which passed through was treated with a concentrated solution of ammonium sulphate. This precipitated the poisons and a number of other substances which gave proteid reactions. After purification and dialysis the poison was obtained as yellow, soluble flakes which no longer gave proteid reactions. It was a substance in which there was no noticeable phosphorus nor sulphur. It was thus proved that the tetanus poison belonged neither to the ptomaines before referred to nor to the proteids. The poison, while not perfectly pure, was purer than any ever before obtained, and was so poisonous that a mouse weighing one-half ounce was killed by $\frac{1}{112800}$ part of a grain, while $\frac{1}{280}$ of a grain should kill a man weighing 150 pounds.

It is not difficult to understand how if the tetanus bacillus outside of the body can produce such powerful poisons, it can give rise in the animal organism to serious troubles. The diphtheria bacillus is another germ which forms very powerful poisons in the solutions upon which it feeds. As already mentioned, some authors, Roux and Yersin, believe that this poison also belongs to the ferments like trypsin and pepsin, while Brieger and Fraenkel thought it was a toxalbumin. We find, after the germ has been removed from the culture liquid by filtration, that the poison can be separated by calcium phosphate or ammonium sulphate, just like the tetanus poison. In the purest condition in which it has been so far obtained it fails to give the proteid reaction, and $\frac{1}{64}$ of a grain will kill a guinea pig. It dialyses readily. Bodies of a similar kind have been obtained from cholera, glanders, swine plague, tuberculosis, and anthrax cultures, while many other bacteria produce soluble intensely poisonous substances in artificial cultures as well as inside the animal body.

These products are all characteristic of the individual organism. The conditions under which the most poisonous ones are formed seem to be dependent partly, we may say, upon the humor of the germ and also upon the food offered for its use. It appears, for example, in connection with the diphtheria germ that if there happens to be present in the beef broth upon which it is being cultivated an undue amount of glucose and an insufficient supply of alkali that, instead of producing

a very active poison, the substance secreted is much less harmful. This is accounted for by the supposition that the glucose is decomposed into acid, which, in its turn, neutralizes or decomposes the poison ordinarily produced by the germ. These poisons, it was originally supposed, resulted from the decomposition of the food of the germ, just as soluble and assimilable albuminoids are produced by the acids and ferments of the animal body from the insoluble albuminoids that are ingested as food. It has been found, however, that in most instances the poison of the germ is in solution in quantity only after the germs themselves have become partially disintegrated. In other words, the active bacterial poisons seem to be products of the cell and retained within the cell until the latter dies and the cell membrane is broken, permitting the passage into the surrounding liquid of the poison. What, then, is the true nature of these poisons if they belong neither to the bases nor to the proteids or toxalbumins? That, unfortunately, is one of the problems to which, up to the present time, chemical research has not been able to give a definite answer: and this because, as we have already noted, the poisons of these bacteria are so tremendously active, and consequently produced in proportionately small amount, even when a large quantity of the culture media is used, that it has so far been a matter almost of impossibility to separate a sufficient quantity of these poisonous principles to purify them perfectly for chemical analysis. Perhaps this object has been attained more nearly than ever before by some workers in the biochemic laboratory in this city, who have succeeded in separating from cultures of the tuberculosis germ a crystalline poison with constant melting point and a constant composition. This is not the only poison produced by the tuberculosis germ, but that it is one of the principles which is responsible for much of the trouble with this disease is beyond doubt. These special poisonous principles, which are so difficult to obtain pure, we designate by the name toxins, to distinguish them from the ptomaines and proteid substances before mentioned. Another difficulty which is always encountered in extracting the poisons of bacteria is their instability. The material with which an experiment is begun may be very poisonous, but the processes of precipitation and extraction through which it must be passed in order to obtain a desired substance are such that often, long before the final stages have been reached, the nature of the poisons has undergone an entire change due to the chemical processes which have necessarily been applied.

We have said that the poisons of the germ were synthetic products which were built up within the cell wall. Some of these easily pass through the cell wall, due, probably, to the greater permeability of the living membrane; others are retained within the cell wall, only to pass into solution when these walls are broken down. Tetanus, diphtheria, and swine plague allow this diffusion to take place very rapidly, while with other germs, like typhoid fever, anthrax, cholera, glanders, tuberculosis, the poison is produced and retained within the cell more firmly

during the life of the latter. As the germs die, however, in artificial cultures, the cell walls gradually disintegrate and the poison passes out into the surrounding liquid. In the case of tuberculosis and glanders a strong solution of these cell poisons in the surrounding liquid upon which the germ has been feeding gives tuberculin and mallein, the two diagnostic agents which have been of inestimable value in detecting latent disease in men and animals and thus preventing the spread of untold evils.

Thus the warfare, first begun by the chemist with the microbes in identifying their character and relation to disease, has been prosecuted for little more than a decade in endeavoring to detect the true character of the insidious poisons with which their arrows are tipped. To a certain extent, as we have seen, this warfare has been a successful one, in so far that the poisons have been hunted and driven to their last stronghold, which ere long, with the many workers in attack, must yield, as heretofore, to superior forces. But while this search for the pure poisons has been in progress the chemist has not been idle in endeavoring to counteract these poisons, the nature of which he did not thoroughly understand, but the evil effects of which were only too apparent. While Jenner, in vaccination for smallpox, and Pasteur, with his method of vaccination for anthrax, had shown that it was possible to protect animals and men from a virulent attack of disease by giving them first a mild attack (though, by the way, there are a few who contend even to day that vaccination is useless), it remained for Salmon, his assistant, and Smith, in this city, to demonstrate, in 1882, that the poisons of germs could be used by men and animals to fortify themselves against the attacks of these same bacteria. This could be accomplished by introducing into the circulation of the animal a small quantity of the poison of the germ, so that when the germ itself was injected the poison which it produced was without effect. What had been found true for one disease of animals proved also to be true for many others, and chemical vaccination was tried for diphtheria, tetanus, anthrax, cholera, typhoid fever, tuberculosis, glanders, and a number of other diseases. But this discovery led to another, important and far-reaching. Fodor showed that the blood serum of animals made immune to a particular disease by injecting the animal with the poison which this germ formed had the effect of destroying the germ of the disease. This excited renewed interest in the study of the blood, and within a few years it was demonstrated by the work of many, some in this city in the laboratory before mentioned, that this serum from previously immunized animals not only had the property of conferring immunity upon other animals, but also of checking the disease after it had once begun. How thoroughly this fact was demonstrated, first by Behring and subsequently by Roux and others, in connection with diphtheria and tetanus has been dwelt upon often, and we know of the many thousands of lives that have been saved by the use of antitoxic serums.

To prepare these the solution of the toxins, which we have before described, are injected into different animals, preferably horses, and at the end of six to twelve weeks the blood of these animals is found to yield a serum containing substances possessing both immunizing and curative properties which we call antitoxins. The active principle of this serum is present in a comparatively small quantity, but its influence is enormous. It does not appear to be a substance which directly chemically neutralizes the poison, but counteracts its effects within the animal in some unknown way.

But some of our friends may ask, Were not these facts discovered first by the use of animals, and hence has not this knowledge, though of inestimable value to mankind, been too dearly bought? Yes, perhaps, a score or two of guinea pigs and sweet, lovely rats and mice have sacrificed their lives for humanity's sake. But this knowledge could not have been gained in any other way unless by the sacrifice of human life. What mother would hesitate to sacrifice a thousand guinea pigs for the life of her child, or, on the other hand, would wish her child to serve as the subject of experiment for others?

I have often been asked if the horses placed under this treatment for the production of antitoxins suffer. I think not, and as an illustration will relate an incident which has come under my own observation in the study of the antitoxins of the dread disease, tuberculosis. A well-blooded horse, gentle in every particular, except that he would run away upon the slightest provocation, seemed to be a suitable subject for some work. Accordingly he received an injection of the poison of the tuberculosis germ, with the expectation that so high-strung an animal would rebel against these pleasant familiarities. But he was entirely too wise for this. He submitted quietly and seemed much interested while by means of an hypodermic syringe a small quantity of the poison was injected beneath his skin. A few days afterwards when the operation was repeated it would have been reasonable to expect that if there had been any discomfort the horse would have rebelled against the procedure. Did this happen? Not by any means. As soon as he observed the doctor appear with the syringe and bottle he trotted toward him with pleasure, stood quietly looking around with intelligence while the injection was made, and ever afterwards lent himself to the experiment with as much evident pleasure and interest as that of the investigators, apparently thoroughly appreciating its object.

It would hardly be fair to say that this dumb animal was endowed with more intelligence than some of our ill-informed but well-meaning friends, and yet would its actions not seem to indicate a high regard for scientific work and disclaimer of suffering?

Is it that they are instigated by a desire to inflict torture that scores of investigators have sacrificed their lives in searching for the poisons of dangerous bacteria and their antitoxins? Is it inhumanity which spurs them on at imminent personal risk in their efforts, which are

daily yielding new and brilliant results, to find means for controlling a disease which annually causes one-seventh of the deaths of the population of the globe?

However, it is not only for protection against the two diseases, tetanus and diphtheria, just mentioned, that antitoxic serums can be prepared. Recent investigations have proved that typhoid fever, cholera, anthrax, the plague, etc., are amenable to similar treatment and in the same department in this city that chemical vaccination received its first impetus, but by workers in the biochemic laboratory it has been demonstrated that two diseases that cause such losses to the farmers of the country may be controlled by antitoxic serums. Investigators in this same laboratory have shown also that a substance antitoxic to tuberculosis can be produced in the serum of animals when they are properly treated, which has undoubted and pronounced effect in checking experimental tuberculosis in small animals.

When we inquire the character of these antitoxins we are almost as yet more in the dark than in our efforts to discover the exact nature of the poisons of germs. However, it has been possible to separate in a fairly pure form the antitoxic principle from diphtheria serum, a minute amount of which will confer immunity and the antitoxic principle of swine plague, 0.002 gram of which has been found to cure animals weighing 1 pound, and even a solid antitoxic-like substance for tuberculosis has been obtained in an impure form. All these solid antitoxic principles resemble each other very closely in their chemical tests and methods of separation, showing albuminoid reactions, but in their curative properties they are totally independent the one of the other. The diphtheria antitoxic serum does not cure tetanus; the swine plague serum does not cure the cholera.

In the case of the venom of serpents it has been found that repeated injections will make the serum of an animal antitoxic and curative against other venoms. The antitoxic serum produced by the cobra venom will protect animals and men against the bite of the rattlesnake as well as its own bite. It would seem from this that there is a very close relationship between the poisons of venomous snakes, and that immunity to one also gives protection from the other. It appears very probable, also, that the poisons of germs belonging to the same genus will be closely allied and that an antitoxin for one will also be an antitoxin for the other. In fact, it has been demonstrated that the products of the bacillus coli communis will protect animals from the typhoid germ, to which it is closely allied. The same effect will probably be obtained with many other diseases where the germs are related.

The difficulty of separating these antitoxins completely from the other constituents of the blood has made it impossible as yet to obtain positive information as to their true chemical character.

As to their action in producing immunity, one theory is that they directly neutralize the poisons which the germs produce, but this does not seem to be substantiated by experiment.

Another theory proposed first by Sternberg, then by Metchnikoff, ascribes immunity to the action of the white blood corpuscles upon the bacteria, while the third theory, and the one which seems most tenable in view of actual results, is that the antitoxic principle partakes of the nature of an unorganized ferment like diastase, and that its action in the body, with the aid of the leucocytes, suffices to render innocuous the poisons of the particular germs.

There is little room for doubt that in the first instance the antitoxins are the result of cell activity upon the introduced poison. Just how the cell manages to convert the toxin into antitoxic ferment is not known, probably by absorption of the toxin and subsequent secretion of the antitoxin within the cell wall. Every added dose of toxin finds not only the leucocytes but a ferment to aid in its decomposition, and so the change proceeds more rapidly and the immunity is increased. Exactly what the chemical alteration in this instance is has not been explained, but that there are oxidation and molecular rearrangement of the toxin seems to be probable.

Thus, without taking into consideration the destruction of the causes of disease, viz, germs themselves, by means of such excellent disinfectants as formaldehyde, has the warfare against the microbes progressed, although as we learn more of the properties and uses of their toxins we are almost forced to confess that it is not a warfare, but rather that man is learning how to train and control these microscopic forms of life as centuries before he learned how to control the animals and higher plants.

Our ideas of germs are so thoroughly associated with disease that we often forget that these germs are but the simplest forms of plant cells which are endowed with various functions. The majority of them are not injurious to man, but very useful fellow-workers if he has once learned how to manage them. The value of this cell life in the production of wines, beer, and other fermented liquids is too well known to need more than passing mention. But you may not all know to what extent the aroma and flavor of butter and cheese are due to the products of micro-organisms. Now these products are frequently ethers and esters, sometimes acid and acid derivatives or amines, the latter a class of compounds to one of which smoked herring owes its particular flavor and which is also formed by a number of bacteria.

When milk is first collected from healthy animals it is almost free from germs, but exposed to the air it soon becomes filled with those forms of life which are perfectly harmless. If placed under suitable conditions with regard to temperature they will multiply very readily and the milk becomes sour, due to the formation of lactic acid produced from the sugar in the milk by one or more of these germs. If the germs present happen to be those giving an ether and ester, which have a pleasant flavor and aroma, good butter can be made, but if they give

rise to the formation of disagreeable thio-ethers, and esters or some amines the butter is poor and bad.

Now, by isolating different germs found in the milk and cultivating them separately, so as to discover their own peculiar product, it is possible to always make butter of the same sort and flavor by first destroying the other germs present by Pasteurization and then inoculating the cream with the particular germs desired. A number of germs have been isolated from milk which will produce good butter, and any one of them is, perhaps, as satisfactory as the other, the ethereal product being slightly different and more palatable to different individuals. Of course a great many germs have been found in milk which produce disagreeable compounds, and it is not possible to tell from their appearance simply which will be desirable plants, but it is easy to cultivate them in a small quantity of milk, note the results, and select the desirable plant cells.

Fortunately or unfortunately, the use of these germs has been patented, so that in the near future we may see branded upon particularly fine butter and cheese "Patented in 1893," "Amended 1896," "Reissued 1908," etc. May we expect soon a patented process for sterilized breathing, eating, and sleeping?

Recently it has been found that malt if inoculated with a particular ferment from the skin of the grape will be converted into wine, the ferment used giving rise to the formation of characteristic ethers, so it is certainly not beyond the limits of possibilities that in the near future American beer after a voyage to France may return as excellent champagne. When we discover too a germ (as had been done recently) that converts starch into cellulose, we are almost led to wonder if it might not be possible to produce cotton in a culture flask if the particular germs were supplied with nutritious food and a sufficient amount of carbon dioxide, oxygen, and water.

The flavor of many luscious fruits and foods is due to the products either directly or indirectly of one or more of these useful bacteria, and on the other hand similar germs play an important and as yet unknown rôle in the formation of poisonous alkaloids.

Many bacteria form beautifully colored substances, reds, yellows, blues, greens, and delicate shades which the art of man has not been able to imitate and the nature of which he has not yet learned. These, too, are only hiding their secrets with a thin veil, which investigation will soon withdraw.

But it is not only in simple industrial processes that the products of germs are important. Man's very existence, while menaced on the one hand by a few germs, is on the other dependent upon their activity. The germs which in the soil produce nitrous and nitric acid and ammonia, and aid their assimilation by the plants, those which facilitate the decomposition of phosphates and bring the phosphorous, a so necessary constituent for the life of plants and animals, into an available form,

and those which aid in the destruction of dead vegetable and animal matter, play a very valuable and but little appreciated part in the continuance of the life and well being of man.

There are many other ways in which the products of these dreaded microscopic cells are useful, but all, a very insignificant number of which we have mentioned, are only waiting man's bidding to become valuable subjects, and to show that, as has been instanced in the history of nations, conquered people often make the best and wisest citizens.

THE RARER METALS AND THEIR ALLOYS.[1]

By Prof. W. CHANDLER ROBERTS-AUSTEN, C. B., F. R. S., M. R. I.

For reason is not the only attribute of man, nor is it the only faculty which he habitually employs for the ascertainment of truth.—G. J. ROMANES.

Appreciation . . . . by æsthetic and intellectual faculties which are not senses, and which are not unfrequently sadly wanting where the senses are in full vigor.—T. H. HUXLEY.

The study of metals possesses an irresistible charm for us, quite apart from its vast national importance. How many of us made our first scientific experiment by watching the melting of lead, little thinking that we should hardly have done a bad life's work if the experiment had been our last, provided we had only understood its full significance. How few of us forget that we wistfully observed at an early age the melting in an ordinary fire of some metallic toy of our childhood; and such an experiment has, like the "Flatiron for a farthing," in Mrs. Ewing's charming story, taken a prominent place in literature which claims to be written for the young. Hans Andersen's fairy tale, for instance, the "History of a tin soldier," has been read by children of all ages and of most nations. The romantic incidents of the soldier's eventful career need not be dwelt upon; but I may remind you that at its end he perished in the flames of an ordinary fire, and all that could subsequently be found of him was a small heart-shaped mass. There is no reason to doubt the perfect accuracy of the story recorded by Andersen, who at least knew the facts, though his statement is made in popular language. No analysis is given of the tin soldier; in a fairy tale it would have been out of place, but the latest stage of his evolution is described, and the record is sufficient to enable us to form the opinion that he was composed of both tin and lead, certain alloys of which metals will burn to ashes like tinder. His uniform was doubtless richly ornamented with gold lace. Some small amount of one of the rarer metals had probably—for on this point the history is silent—found its way into his constitution, and by uniting with the gold formed the heart-shaped mass which the fire would not melt, as its

[1] Read at weekly evening meeting of Royal Institution of Great Britain, March 15, 1895. Printed in Proceedings of the Institution, Vol XIV, pp. 497–520.

temperature could not have exceeded 1,000° C.; for we are told that the golden rose worn by the artiste who shared the soldier's fate was also found unmelted. The main point is, however, that the presence of one of the rarer metals must have endowed the soldier with his singular endurance, and in the end left an incorruptible record of him.

This incident has been taken as the starting point of the lecture, because we shall see that the ordinary metals so often owe remarkable qualities to the presence of a rarer metal which fits them for special work.

This early love of metals is implanted in us as part of our "unsquandered heritage of sentiments and ideals which has come down to us from other ages," but future generations of children will know far more than we did; for the attempt will be made to teach them that even psychology is a branch of molecular physics, and they will therefore see much more in the melted toy than a shapeless mass of tin and lead. It is really not an inert thing; for some time after it was newly cast it was the scene of intense molecular activity. It probably is never molecularly quiescent, and a slight elevation of temperature will excite in it rapid atomic movement anew. The nature of such movement I have indicated on previous occasions when, as now, I have tried to interest you in certain properties of metals and alloys.

This evening I appeal incidentally to higher feelings than interest by bringing before you certain phases in the life history of metals which may lead you to a generous appreciation of the many excellent qualities they possess.

Metals have been sadly misunderstood. In the belief that animate beings are more interesting, experimenters have neglected metals, while no form of matter in which life can be recognized is thought to be too humble to receive encouragement. Thus it is that bacteria, with repulsive attributes and criminal instincts, are petted and watched with solicitude, and comprehensive schemes are submitted to the Royal Society for their devolopment, culture, and even for their "education,"[1] which may, it is true, ultimately make them useful metallurgical agents, as certain micro-organisms have already proved their ability to produce arseniuretted hydrogen from oxide of arsenic.[2]

It will not be difficult to show that methods which have proved so fruitful in results when applied to the study of living things are singularly applicable to metals and alloys, which really present close analogies to living organisms. This must be a new view to many, and it may be said, "it is well known that uneducated races tend to personify or animate external nature," and it is strange, therefore, to attempt, before a cultured audience, to trace analogies which must appear to be remote between moving organisms and inert alloys, but

[1] Dr. Percy Frankland especially refers to the "education" of bacilli for adapting them to altered conditions. Roy. Soc. Proc., Vol. LVI, 1894, page 539.

[2] Dr. Brauner. Chem. News, Feb. 15, 1895, page 79.

"the greater the number of attributes that attach to anything, the more real that thing is."[1] Many of the less-known metals are very real to me, and I want them to be so to you; listen to me, then, as speaking for my silent metallic friends, while I try to secure for them your sympathy, esteem, and intuitive perception of their beauty.

First, as regards their origin and early history. I fully share Mr. Lockyer's belief as to their origin, and think that a future generation will speak of the evolution of metals as we now do of that of animals, and that observers will naturally turn to the sun as the field in which this evolution can best be studied.

To the alchemists metals were almost sentient; they treated them as if they were living beings, and had an elaborate pharmacopœia of "medicines" which they freely administered to metals in the hope of perfecting their constitution. If the alchemists constantly drew parallels between living things and metals, it is not because they were ignorant, but because they recognized in metals the possession of attributes which closely resemble those organisms. "The first alchemists were gnostics, and the old beliefs of Egypt blended with those of Chaldea in the second and third centuries. The old metals of the Egyptians represented men, and this is probably the origin of the *homunculus* of the middle ages, the notion of the creative power of metals and that of life being confounded in the same symbol."[2]

Thus Albertus Magnus traces the influence of congenital defects in the generation of metals and of animals, and Basil Valentine symbolizes the loss of metalline character, which we now know is due to oxidation, to the escape from the metal of an indestructible spirit which flies away and becomes a soul. On the other hand, the "reduction" of metals from their oxides was supposed to give the metals a new existence.[3] A poem of the thirteenth century well embodies this belief in the analogies between men and metals, in the quaint lines:

> Homs ont l'estre comme metaulx,
> Vie et augment des vegetaulx.
> Instinct et sens comme les bruts,
> Esprit comme ange en attributs.

"Men have being"—constitution—like metals; you see how closely metals and life were connected in the minds of the alchemists, and we inherit their traditions.

"Who said these old renowns, dead long ago, could make me forget the living world?" are words which Browning places in the lips of Paracelsus, and we metallurgists are not likely to forget the living

[1] Lotze, "Metaphysic," section 49, quoted by Illingworth. "Personality, Human and Divine." Bampton Lectures, 1894, page 43.

[2] Berthelot, Les Origines de l'Alchimie, 1885 page 60.

[3] Les Remonstrances ou la Complainte de Nature a l'Alchymiste Errant. Attributed to Jehan de Meung, who with Guillaume de Lorris wrote the Roman de la Rose. M. Meon, the editor of the edition of 1814 of this celebrated work, doubts, however, whether the attribution of the *complainte de nature*, to Meung is correct.

world; we borrow its definitions, and apply them to our metals. Thus nobility in metals as in men, means freedom from liability to tarnish, and we know that the rarer metals are like rarer virtues, and have singular power in enduring their more ordinary associates with firmness, elasticity, strength, and endurance. On the other hand, some of the less known metals appear to be mere "things" which do not exist for themselves, but only for the sake of other metals to which they can be united. This may, however, only seem to be the case because we as yet know so little about them. The question naturally arises, how can the analogies between organic and inorganic bodies now be traced? I agree with my colleague at the École des Mines of Paris, Prof. Urbain Le Verrier, in thinking that it is possible[1] to study the biology, the anatomy, and even the pathology of metals.

The anatomy of metals—that is, their structure and framework—is best examined by the aid of the microscope, but if we wish to study the biology and pathology of metals, the method of autographic pyrometry, which I brought before you in a Friday evening lecture delivered in 1892, will render admirable service, for, just as in biological and pathological phenomena vital functions and changes of tissue are accompanied by a rise or fall in temperature, so molecular changes in metals are attended with an evolution or absorption of heat. With the aid of the recording pyrometer we now "take the temperature" of a mass of metal or alloy in which molecular disturbance is suspected to lurk, as surely as a doctor does that of a patient in whom febrile symptoms are manifest.

It has, moreover, long been known that we can submit a metal or an alloy in its normal state to severe stress, record its power of endurance, and then, by allowing it to recover from fatigue, enable it to regain some, at least, of its original strength. The human analogies of metals are really very close indeed, for, as is the case with our own mental efforts, the internal molecular work which is done in metals often strengthens and invigorates them. Certain metals have a double existence, and according to circumstances, their behavior may be absolutely harmful or entirely beneficial. The dualism we so often recognize in human life becomes allotropism in metals, and they, strangely enough, seem to be restricted to a single form of existence if they are absolutely free from contamination, for probably an absolutely pure metal can not pass from a normal to an allotropic state. Last, it may be claimed that some metals possess attributes which are closely allied to moral qualities, for, in their relations with other elements, they often display an amount of discrimination and restraint that would do credit to sentient beings.

Close as this resemblance is, I am far from attributing consciousness to metals, as their atomic changes result from the action of external agents, while the conduct of conscious beings is not determined from

[1] La Métallurgie en France, 1894, page 2.

without, but from within. I have, however, ventured to offer the introduction of this lecture in its present form, because any facts which lead us to reflect on the unity of plan in nature, will aid the recognition of the complexity of atomic motion in metals upon which it is needful to insist.

The foregoing remarks have special significance in relation to the influence exerted by the rarer metals on the ordinary ones. With the exception of the action of carbon upon iron, probably nothing is more remarkable than the action of the rare metals on those which are more common; but their peculiar influence often involves, as we shall see, the presence of carbon in the alloy.

Which, then, are the rarer metals, and how may they be isolated? The chemist differs somewhat from the metallurgist as to the application of the word "rare." The chemist thinks of the "rarity" of a compound of a metal; the metallurgist, rather of the difficulty of isolating the metal from the state of combination in which it occurs in nature.

The chemist in speaking of the reactions of salts of the rarer metals, in view of the wide distribution of limestone and pyrolusite, would hardly think of either calcium or manganese as being among the rarer metals. The metallurgist would consider pure calcium or pure manganese to be very rare. I have only recently seen comparatively pure specimens of the latter.

The metals which, for the purposes of this lecture, may be included among the rarer metals are: (1) Those of the platinum group, which occur in nature in the metallic state; and (2) certain metals which in nature are usually found as oxides or in an oxidized form of some kind, and these are chromium, manganese, vanadium, tungsten, titanium, zirconium, uranium, and molybdenum (which occurs, however, as sulphide). Incidental reference will be made to nickel and cobalt.

Of the rare metals of the platinum group I propose to say but little. We are indebted for a magnificent display of them in the library of my friends, Messrs. George and Edward Matthey, and to Mr. Sellon, all members of a great firm of metallurgists. You should specially look at the splendid mass of palladium, extracted from native gold of the value of £2,500,000, at the melted and rolled iridium, and at the masses of osmium and rhodium. No other nation in the world could show such specimens as these, and we are justly proud of them.

These metals are so interesting and precious in themselves, that I hope you will not think I am taking a sordid view of them by saying that the contents of the case exhibited in the library are certainly not worth less than £10,000.

As regards the rarer metals which are associated with oxygen, the problem is to remove the oxygen, and this is usually effected either by affording the oxygen an opportunity for uniting with another metal, or by reducing the oxide of the rare metal by carbon, aided by the tearing

effect of an electric current. In this crucible there is an intimate mixture, in atomic proportions, of oxide of chromium and finely divided metallic aluminum. The thermo junction (A, fig. 1, Pl. XXIII) of the pyrometer which formed the subject of my last Friday evening lecture here is placed within the crucible B, and the spot of light C, from the galvanometer D, with which the junction is connected, indicates on the screen that the temperature is rising. You will observe that as soon as the point marked 1,010° is reached energetic action takes place; the temperature suddenly rising above the melting point of platinum, melts the thermo junction, and the spot of light swings violently: but if the crucible be broken open you will see that a mass of metallic chromium has been liberated.

The use of alkaline metals in separating oxygen from other metals is well known. I can not enter into its history here, beyond saying that if I were to do so, frequent references to the honored names of Berzelius, Wöhler, and Winkler would be demanded.[1]

Mr. Vautin has recently shown that granulated aluminum may readily be prepared, and that it renders great service when employed as a reducing agent. He has lent me many specimens of rarer metals which have been reduced to the metallic state by the aid of this finely-granulated aluminum; and I am indebted to his assistant, Mr. Picard, who was lately one of my own students at the Royal School of Mines, for aid in the preparation of certain other specimens which have been isolated in my laboratory at the mint.

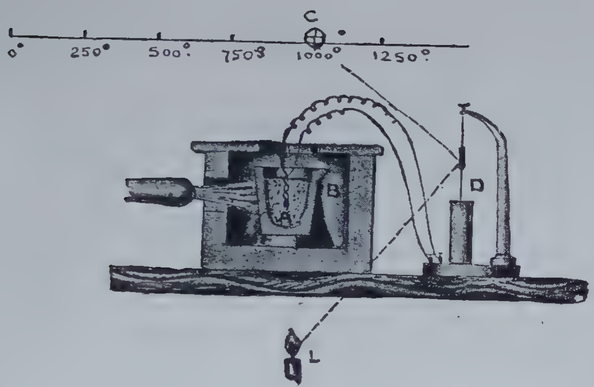
The experiment you have just seen enables me to justify a statement I made respecting the discriminating action which certain metals appear to exert. The relation of aluminum to other metals is very singular. When, for instance, a small quantity of aluminum is present in cast iron, it protects the silicon, manganese, and carbon from oxidation.[2] The presence of silicon in aluminum greatly adds to the brilliancy with which aluminum itself oxidizes and burns.[3] It is also asserted that aluminum, even in small quantity, exerts a powerful protective action against the oxidation of the silver-zinc alloy, which is the result of the desilverization of lead by zinc.

Moreover, heat aluminum in mass to redness in air, where oxygen may be had freely, and a film of oxide which is formed will protect the mass from further oxidation. On the other hand, if finely divided aluminum finds itself in the presence of an oxide of a rare metal, at an elevated temperature, it at once acts with energy and promptitude, and releases the rare metal from the bondage of oxidation. I trust, therefore, you will consider my claim that a metal may possess moral attributes has been justified. Aluminum, moreover, retains the oxygen it

[1] An interesting paper, by H. F. Keller, on the reduction of oxides of metals by other metals, will be found in the Journal of the American Chemical Society, December, 1894, page 833.

[2] Bull. Soc. Chim. Paris, Vol. XI, 1894, page 377.

[3] Ditte, Leçons sur les Métaux, Part II, 1891, page 206.



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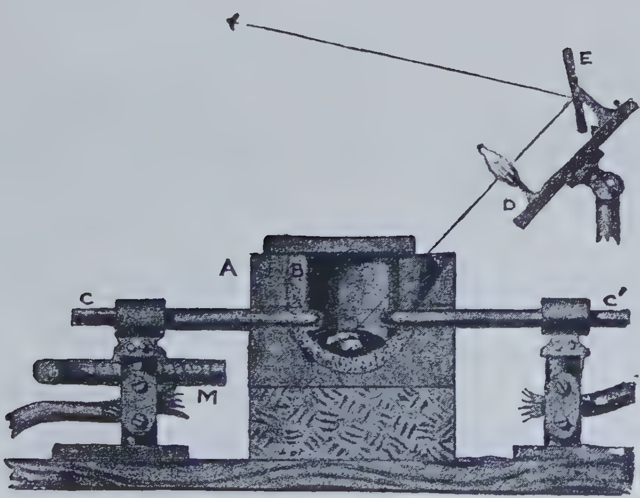


2

RARER METALS AND THEIR ALLOYS.

has acquired with great fidelity, and will only part with it again by electrolytic action, or at very high temperatures under the influence of the electric arc in the presence of carbon.

[A suitable mixture of red lead and aluminum was placed in a small crucible heated in a wind furnace, and in two minutes an explosion announced the termination of the experiment. The crucible was shattered to fragments.]

The aluminum loudly protests, as it were, against being intrusted with such an easy task, as the heat engendered by its oxidation had not to be used in melting a difficultly fusible metal like chromium, the melting point of which is higher than that of platinum.

It is admitted that a metal will abstract oxygen from another metal if the reaction is more exothermic than that by which the oxide to be decomposed was originally formed. The heat of formation of alumina is 391 calories, that of oxide of lead is 51 calories; so that it might be expected that metallic aluminum, at an elevated temperature, would readily reduce oxide of lead to the metallic state.

The last experiment, however, proved that the reduction of oxide of lead by aluminum is effected with explosive violence, the temperature engendered by the reduction being sufficiently high to volatilize the lead. Experiments of my own show that the explosion takes place with much disruptive power when aluminum reacts on oxide of lead in vacuo, and that if coarsely ground, fused litharge be substituted for red lead, the action is only accompanied by a rushing sound. The result is, therefore, much influenced by the rapidity with which the reaction can be transmitted throughout the mass. It is this kind of experiment which makes us turn with such vivid interest to the teaching of the school of St. Claire Deville, the members of which have rendered such splendid services to physics and metallurgy. They do not advocate the employment of the mechanism of molecules and atoms in dealing with chemical problems, but would simply accumulate evidence as to the physical circumstances under which chemical combination and dissociation take place, viewing these as belonging to the same class of phenomena as solidification, fusion, condensation, and evaporation. They do not even insist upon the view that matter is minutely granular, but in all cases of change of state make calculations on the basis of work done, viewing changed "internal energy" as a quantity which should reappear when the system returns to the initial state.

A verse of some historical interest may appeal to them. It occurs in an old poem to which I have already referred as being connected with the "Roman de la Rose," and it expresses nature's protest against those who attempt to imitate her works by the use of mechanical methods. The "argument" runs thus:

Comme Nature se complaint,
Et dit sa douleur et son plaint
A ung sot souffleur sophistique
Qui n'use que d'art méchanique.

If the "use of mechanical art" includes the study of chemistry on the basis of the mechanics of the atoms, I may be permitted to offer the modern school the following rendering of nature's plaint:

How nature sighs without restraint,
And grieving makes her sad complaint
Against the subtle sophistry
Which trusts atomic theory.

An explosion such as is produced when aluminum and oxide of lead are heated in presence of each other, which suggested the reference to the old French verse, does not often occur, as in most cases the reduction of the rarer metals by aluminum is effected quietly.

Zirconium is a metal which may be so reduced. I have in this way prepared small quantities of zirconium from its oxide, and have formed a greenish alloy of extraordinary strength by the addition of 0.2 per cent of it to gold, and there are many circumstances which lead to the belief that the future of zirconium will be brilliant and useful. I have reduced vanadium and uranium from its oxide by means of aluminum as well as manganese, which is easy, and titanium, which is more difficult. Tungsten, in fine specimens, is also before you, and allusion will be made subsequently to the uses of these metals At present I would draw your attention to some properties of titanium which are of special interest. It burns with brilliant sparks in air; and, as few of us have seen titanium burn, it may be well to burn a little in this flame. [Experiment performed.] Titanium appears to be, from the recent experiments of M. Moissan, the most difficultly fusible metal known; but it has the singular property of burning in nitrogen—it presents, in fact, the only known instance of vivid combustion in nitrogen.[1]

Titanium may be readily reduced from its oxide by the aid of aluminum. Here are considerable masses, sufficiently pure for many purposes, which I have recently prepared in view of this lecture.

The other method by which the rarer metals may be isolated is that which involves the use of the electrical furnace. In this connection the name of Sir W. Siemens should not be forgotten. He described the use of the electric arc furnace in which the carbons were arranged vertically, the lower carbon being replaced by a carbon crucible; and in 1882 he melted in such a furnace no less than 10 pounds of platinum during an experiment at which I had the good fortune to assist. It may fairly be claimed that the large furnaces with a vertical carbon in which the bath is maintained fluid by means of the electric current, the aluminum and other metals being reduced by electrolytic action, are the direct outcome of the work of Siemens.

In the development of the use of the electric arc for the isolation of the rare, difficultly fusible metals Moissan stands in the front rank.

[1] Lord Rayleigh has since stated that titanium does not combine with argon, and M. Guntz points out that lithium in combining with nitrogen produces incandesence. M. Moissan has also shown that uranium does not absorb argon.

He points out[1] that Despretz[2] used in 1849 the heat produced by the arc of a powerful pile; but Moissan was the first to employ the arc in such a way as to separate its heating effect from the electrolytic action it exerts. This he does by placing the poles in a horizontal position and by reflecting their heat into a receptacle below them. He has shown, in a series of classical researches, that employing 800 ampères and 110 volts a temperature of at least 3,500° may be attained and that many metallic oxides which until recently were supposed to be irreducible may be readily made to yield the metal they contain.[3]

A support or base for the metal to be reduced is needed, and this is afforded by magnesia, which appears to be absolutely stable at the utmost temperatures of the arc. An atmosphere of hydrogen may be employed to avoid oxidation of the reduced metal, which, if it is not a volatile one, remains at the bottom of the crucible almost always associated with carbon—forming, in fact, a carbide of the metal. I want to show you the way in which the electric furnace is used, but, unfortunately, the reductions are usually very tedious, and it would be impossible to actually show you much if I were to attempt to reduce before you any of the rarer metals; but as the main object is to show you how the furnace is used, it may be well to boil some silver at a temperature of some 2,500°, and subsequently to melt chromium in the furnace (fig. 2, Pl. XXIII). This furnace consists of a clay receptacle A lined with magnesia B. A current of 60 ampères and 100 volts is introduced by the carbon poles C, C C′; an electro-magnet M is provided to deflect the arc on to the metal to be melted. [By means of a lens and mirror D E the image of the arc and of the molten metal was projected onto a screen. For this purpose it was found convenient to make the furnace much deeper than would ordinarily be the case.]

The result is very beautiful, but can only be rendered in dull tones by the accompanying illustrations (Pl. XXIV). It may be well, therefore, to state briefly what is seen when the furnace is arranged for the melting of metallic chromium. Directly the current is passed the picture reflected by the mirror E (fig. 2, Pl. XXIII) shows the interior of the furnace (fig. 1, Pl. XXIV) as a dark crater, the dull red poles revealing the metallic luster and gray shadows of the metal beneath them. A little later these poles become tipped with dazzling white, and in the course of a few minutes the temperature rises to about 2,500° C. Such a temperature will keep chromium well melted, though a thousand

[1] Ann. de Chim. et de Phys., Vol. IV, 1895, page 365.

[2] Comptes Rendus, Vol. XXVIII, page 755, and Vol. XXIX, 1849, pages 48, 545, 712.

[3] The principal memoirs of M. Moissan will be found in the Comptes Rendus, Vol. CXV, 1892, page 1031; ibid., Vol. CXVI, 1893, pages 347, 349, 519, 1222, 1225, 1429; ibid., Vol. CXIX, 1894, pages, 15, 20, 935; ibid., Vol. CXX, 1895, page 290. The more important of the metals he has isolated are uranium, chromium, manganese, zirconium, molybdenum, tungsten, vanadium, and titanium. There is an important paper by him on the various forms of the electric furnace in the Ann. de Chim. et de Phys., Vol. IV., 1895, page 365.

degrees more may readily be attained in a furnace of this kind. Each pole is soon surrounded with a lambent halo of the green-blue hue of the sunset, the central band of the arc changing rapidly from peach blossom to lavender and purple. The arc can then be lengthened, and as the poles are drawn farther and farther asunder the irregular masses of chromium fuse in silver droplets below an intense blue field of light, passing into green of lustrous emerald. Then the last fragments of chromium melt into a shining lake, which reflects the glowing poles in a glory of green and gold, shot with orange hues. Still a few minutes later, as the chromium burns, a shower of brilliant sparks of metal are projected from the furnace, amid the clouds of russet or brown vapors which wreath the little crater, while if the current is broken and the light dies out you wish that Turner had painted the limpid tints and that Ruskin might describe their loveliness.

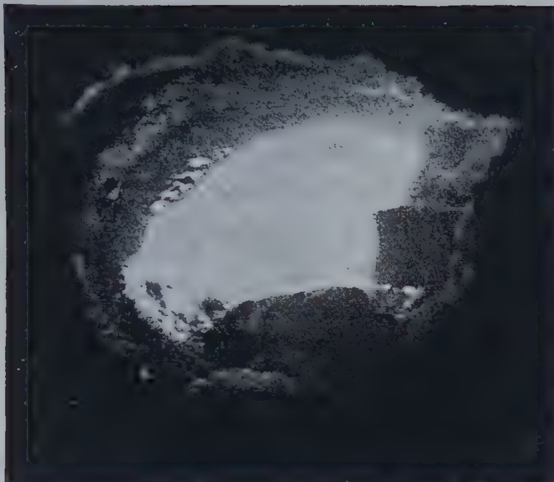
The effect when either tungsten or silver (fig. 2, Pl. XXIV) replaces chromium is much the same, but, in the latter case, the glowing lake is more brilliant in its turbulent boiling, and blue vapors rise to be condensed in the iridescent beads of distilled silver which stud the crater walls.

Such experiments will probably lend a new interest to the use of the arc in connection with astronomical metallurgy, for, as George Herbert said long ago,

> Stars have their storms even in a high degree,
> As well as we;

and Lockyer has shown how important it is, in relation to such storms, to be able to study the disturbances in the various strata of the stellar or solar atmosphere. Layers of metallic vapor which differ widely in temperature can be more readily obtained by the use of the electrical furnace than when a fragment of metal is melted and volatilized by placing it in the arc on the lower carbon.

It must not be forgotten that the use of the electric arc between carbon poles renders it practically impossible to prepare the rare metals without associating them with carbon, often forming true carbides; but it is possible in many cases to separate the carbon by subsequent treatment. Moissan has, however, opened up a vast field of industrial work by placing at our disposal practically all the rarer infusible metals which may be reduced from oxides, and it is necessary for us now to consider how we may best enter upon our inheritance. Those members of the group which we have known long enough to appreciate are chromium and manganese, and these we have only known free from carbon for a few months. In their carburized state they have done excellent service in connection with the metallurgy of steel; and may we not hope that vanadium, molybdenum, titanium, and uranium will render still greater services? My object in this lecture is mainly to introduce you to these metals, which hitherto few of us have ever seen except as minute cabinet specimens, and we are greatly



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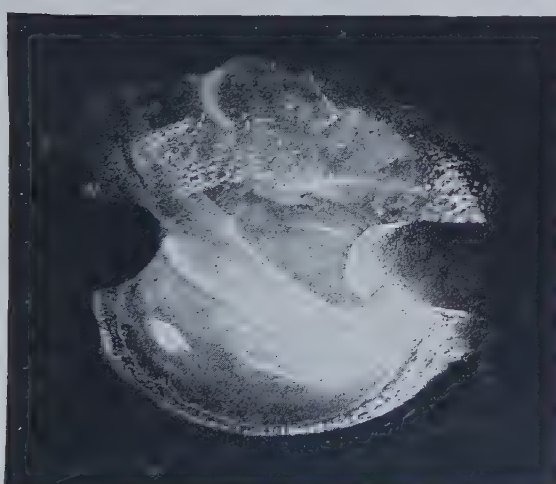
Interior of furnace containing molten chromium, as is seen either by reflection on a screen or by looking into the furnace from above, the eyes being suitably protected by deeply tinted glasses.



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In this case the arc was broken just before the photograph was taken. The furnace contained a bath of silver just at its boiling point. The reflection of the poles in the bath, the globules of distilled silver, and the drifting cloud of silver vapor, are well shown.

indebted to M. Moissan for sending us beautiful specimens of chromium, vanadium, uranium, zirconium, tungsten, molybdenum, and titanium. [These were exhibited.]

The question naturally arises, Why is the future of their usefulness so promising? Why are they likely to render better service than the common metals with which we have long been familiar? It must be confessed that as yet we know but little what services these metals will render when they stand alone; we have yet to obtain them in a state of purity, and have yet to study their properties, but when small quantities of any of them are associated or alloyed with other metals there is good reason to believe that they will exert a very powerful influence. In order to explain this, I must appeal to the physical method of inquiry to which I have already referred.

It is easy to test the strength of a metal or of an alloy; it is also easy to determine its electrical resistance. If the mass stands these tests well, its suitability for certain purposes is assured; but a subtle method of investigation has been afforded by the results of a research intrusted to me by a committee of the Institution of Mechanical Engineers, over which Dr. Anderson, of Woolwich, presides. We can now gather much information as to the way in which a mass of metal has arranged itself during the cooling from a molten condition, which is the necessary step in fashioning it into a useful form; it is possible to gain insight into the way in which a molten mass of a metal or an alloy molecularly settles itself down to its work, so to speak, and we can form conclusions as to its probable sphere of usefulness.

The method is a graphic one, such as this audience is familiar with, for Prof. Victor Horsley has shown in a masterly way that traces on smoked paper may form the record of the heart's action under the disturbing influence caused by the intrusion of a bullet into the human body. I hope to show you by similar records the effect, which, though disturbing, is often far from prejudicial, of the introduction of a small quantity of a foreign element into the "system" of a metal, and to justify a statement which I made earlier as to the applicability of physiological methods of investigation to the study of metals. In order that the nature of this method may be clear, it must be remembered that if a thermometer or a pyrometer, as the case may be, is plunged into a mass of water or of molten metal, the temperature will fall continuously until the water or the metal begins to become solid; the temperature will then remain constant until the whole mass is solid, when the downward course of the temperature is resumed. This little thermo-junction is plunged into a mass of gold, an electric current is, in popular language, generated, and the strength of the current is proportional to the temperature to which the thermo-junction is raised; so that the spot of light from a galvanometer to which the thermo-junction is attached enables us to measure the temperature, or, by the aid of photography, to record any thermal changes that may occur in a heated mass of metal or alloy.

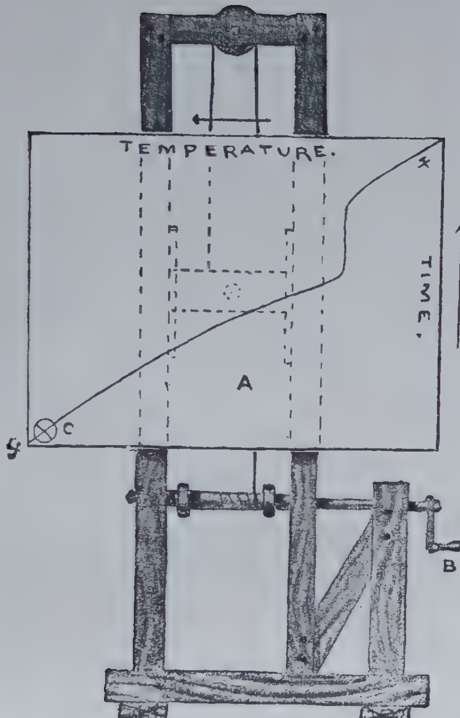
It is only necessary for our purpose to use a portion of the long scale, which may be traced across the end of the room by the spot of light from the galvanometer, but we must make that portion of the scale movable. Let me try to trace before you the curve of the freezing of pure gold. It will be necessary to mark the position occupied by the movable spot of light at regular intervals of time during which the gold is near 1,045° C., that is, while the metal is becoming solid. Every time a metronome beats a second, the white screen A (fig. 1, Pl. XXV), a sheet of paper, will be raised a definite number of inches by the gearing and handle B, and the position successively occupied by the spot of light C will be marked by hand.

You see that the time-temperature curve, $x\ y$, so traced is not continuous. The freezing point of the metal is very clearly marked by the vertical portion. If the gold is very pure the angles are sharp; if it is impure they are rounded. If the metal had fallen below its freezing point without actually becoming solid, that is, if superfusion, or surfusion, had occurred, then there would be, as is often the case, a dip where the freezing begins, and then the temperature curve rises suddenly.

If the metal is alloyed with large quantities of other metals, then there may be several of these freezing points, as successive groups of alloys fall out of solution. The rough diagrammatic method is not sufficiently delicate to enable me to trace the subordinate points, but they are of a vital importance to the strength of the metal or alloy, and photography enables us to detect them readily.

Take the case of the tin-copper series; you will see that as a mass of tin-copper alloy cools, there are at least two distinct freezing points. At the upper one the main mass of the fluid alloy became solid; at the lower, some definite group of tin and copper atoms fall out, the position of the lower point depending upon the composition of the mass.

Now turn to more complex curves taken on one plate by making the sensitized photographic plate seize the critical part of the curve, the range of the swing of the mirror from hot to cold being some 60 feet. The upper curve (fig. 2, Pl. XXV) gives the freezing point of bismuth, and you see that surfusion, a, is clearly marked, the temperature at which bismuth freezes being 268° C. The lower curve, marked "tin," represents the freezing point of that metal, which we know is 231° C., and in it surfusion, b, is also clearly marked. The curve marked standard gold contains a subordinate point, c, which you will observe is lower than the freezing point of tin, and it is caused by the solidification of a small portion of bismuth, which alloyed itself with some gold atoms, and remained fluid below the freezing point not only of bismuth itself but of tin. Now gold with a low freezing point in it like this is found to be very brittle, and we are in a fair way to answer the question why 0.2 per cent of zirconium doubles the strength of gold, while 0.2 per cent of thallium, another rare metal, halves the strength. In the case of the



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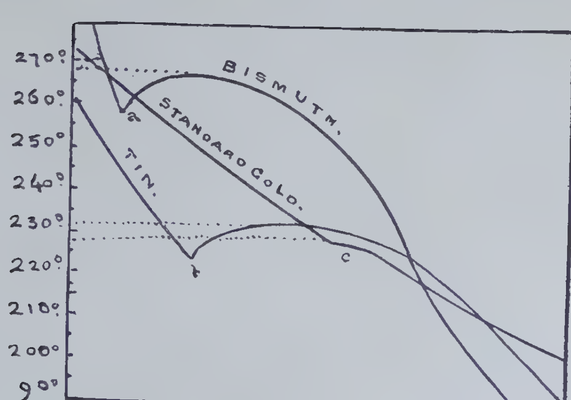


2

RARER METALS AND THEIR ALLOYS.

zirconium the subordinate point is very high up, while in the case of the thallium it is very low down. So far as my experiments have as yet been carried, this seems to be a fact which underlies the whole question of the strength of metals and alloys. If the subordinate point is low, the metal will be weak; if it is high in relation to the main setting point, then the metal will be strong, and the conclusion of the whole matter is this: The rarer metals which demand for their isolation from their oxides either the use of aluminum or the electric arc, never, so far as I can ascertain, produce low freezing points when they are added in small quantities to those metals which are used for constructive purposes. The difficultly fusible rarer metals are never the cause of weakness, but always confer some property which is precious in industrial use. How these rarer metals act, why the small quantities of the added rare metals permeate the molecules, or, it may be the atoms, and strengthen the metallic mass, we do not know; we are only gradually accumulating evidence which is afforded by this very delicate physiological method of investigation.

As regards the actual temperatures represented by points on such curves, it will be remembered that the indications afforded by the recording pyrometer are only relative, and that gold is one of the most suitable metals for enabling a high, fixed point to be determined. There is much trustworthy evidence in favor of the adoption of 1,045° as the melting point hitherto accepted for gold. The results of recent work indicate, however, that this is too low, and it may prove to be as high as 1,061.7, which is the melting point given by Heycock and Neville[1] in the latest of their admirable series of investigations, to which reference was made in my Friday evening lecture of 1892.

It may be well to point to a few instances in which the industrial use of such of the rarer metals as have been available in sufficient quantity is made evident. Modern developments in armor plate and projectiles will occur to many of us at once. This diagram (fig. 1, Pl. XXVI) affords a rapid view of the progress which has been made; and in collecting the materials for it from various sources I have been aided by Mr. Jenkins. The effect of projectiles of approximately the same weight, when fired with the same velocity against 6-inch plates, enables comparative results to be studied, and illustrates the fact that the rivalry between artillerists who design guns, and metallurgists who attempt to produce both impenetrable armor plates and irresistible projectiles, forms one of the most interesting pages in our national history. When metallic armor was first applied to the sides of war vessels it was of wrought iron, and proved to be of very great service by absolutely preventing the passage of ordinary cast-iron shot into the interior of the vessel, as was demonstrated through the American civil war. It was found to be necessary, in order to pierce the plates, to employ harder and larger projectiles than those then in use, and the chilled cast-iron

[1] Trans. Chem. Soc., Vol. LXVII, 1895, p. 160.

shot with which Colonel Palliser's name is identified proved to be formidable and effective. The point of such a projectile was sufficiently hard to retain its form under impact with the plate, and it was only necessary to impart a modern velocity to a shot to enable it to pass through the wrought-iron armor (A, fig. 1, Pl. XXVI).

It soon became evident that, in order to resist the attack of such projectiles with a plate of any reasonable thickness, it would be necessary to make the plate harder, so that the point of the projectile should be damaged at the moment of first contact, and the reaction to the blow distributed over a considerable area of the plate. This object should be attained by either using a steel plate in a more or less hardened condition, or by employing a plate with a very hard face of steel and a less hard but tougher back. The authorities in this country during the decade 1880–90, had a very high opinion of plates that resisted attack without the development of through cracks, and this led to the production of the compound plate. The backs of these plates (B, fig. 1, Pl. XXVI) are of wrought iron, the fronts are of a more or less hard variety of steel, either cast on or welded on by a layer of steel of an intermediate quality, cast between the two plates. Armor plates of this kind differ in detail, but the principle of their construction is now generally accepted as correct.

Such plates shown by the Plate B resisted the attack of large Palliser shells admirably, as when such shells struck the plate they were damaged at their points, and the remainder of the shell was unable to perforate the armor against which it was directed. An increase in the size of the projectiles led, however, to a decrease in the resisting power of the plates, portions of the hard face of which would, at times, be detached in flakes from the junction of the steel and the iron. An increase in the toughness of the projectiles by a substitution of forged chrome steel for chilled iron (see lower part of Plate B) secured a victory for the shot, which was then enabled to impart its energy to the plate faster than the surface of the plate itself could transmit the energy to the back. The result was that the plate was overcome, as it were, piecemeal; the steel surface was not sufficient to resist the blow itself and was shattered, leaving the projectile an easy victory over the soft back. The lower part of Plate B (in fig. 1, Pl. XXVI) represents a similar plate to that used in the Nettle trials of 1888.[1] It must not be forgotten, in this connection, that the armor of a ship is but little likely to be struck twice by heavy projectiles in the same place, although it might be by smaller ones.

Plates made entirely of steel, on the other hand, were found, prior to 1888, to have a considerable tendency to break up completely when struck by the shot. It was not possible, on that account, to make their faces as hard as those of compound plates: but while they did not resist the Palliser shot nearly as well as the rival compound plate, they

[1] Proceedings Institution Civil Engineers, 1889, Vol. XCVIII, page 1 et seq.

offered more effective resistance to steel shot (see lower part of Plate C, fig. 1, Pl. XXVI).

It appears that Berthier recognized, in 1820, the great value of chromium when alloyed with iron; but its use for projectiles, although now general, is of comparatively recent date, and these projectiles now commonly contain from 1.2 to 1.5 per cent of chromium, and will hold together even when they strike steel plates at a velocity of 2,000 feet per second [1] (see lower part of Plate D); and unless the armor plate is of considerable thickness, such projectiles will even carry bursting charges of explosives through it. [The behavior of a chromium-steel shell, made by Mr. Hadfield, was dwelt upon, and the shell was exhibited.]

It now remained to be seen what could be done in the way of toughening and hardening the plates so as to resist the chrome-steel shot. About the year 1888 very great improvements were made in the production of steel plates. Devices for hardening and tempering plates were ultimately obtained, so that the latter was hard enough throughout their substance to give them the necessary resisting power without such serious cracking as had occurred in previous ones. But in 1889 Mr. Riley exhibited, at the meeting of the Iron and Steel Institute, a thin plate that owed its remarkable toughness to the presence of nickel in the steel. The immediate result of this was that plates could be made to contain more carbon, and hence be harder, without at the same time having increased brittleness; such plates, indeed, could be water-hardened and yet not crack.

The Plate E represents the behavior of nickel-steel armor. It will be seen that it is penetrated to a much less extent than in the former case. At the same time there is entire absence of cracking.

Now, as to the hardening processes. Evrard had developed the use of the lead bath in France, while Captain Tressider [2] had perfected the use of the water-jet in England for the purpose of rapidly cooling the heated plates. The principle adopted in the design of the compound plates has been again utilized by Harvey, who places the soft-steel or nickel-steel plate in a furnace of suitable construction, and covers it with carbonaceous material, such as charcoal, and strongly heats it for a period, which may be as long as one hundred and twenty hours. This is the old Sheffield process of cementation, and the result is to increase the carbon from 0.35 per cent in the body of the plate to 0.6 per cent or even more at the front surface, the increase in the amount of carbon extending to a depth of only 2 or 3 inches in the thickest armor.

The carburized face is then "chill-hardened," the result being that the best chrome-steel shot are shattered at the moment of impact, unless they are of very large size as compared with the thickness of the plate. The interesting result was observed lately [3] of shot doing

[1] Journal United States Artillery, 1893, Vol. II, page 497.

[2] Weaver. Notes on Armour, Journal United States Artillery, Vol. III, 1894, page 417.

[3] Brassey's Naval Annual, 1894, page 367.

less harm to the plate and penetrating less, when its velocity was increased beyond a certain value, a result due to a superiority in the power of the face of the plate to transmit energy over that possessed by the projectile, which was itself damaged, when a certain rate was exceeded. At a comparatively low velocity the point of the shot would resist fracture, but the energy of the projectile is not then sufficient to perforate the plate, which would need the attack of a much larger gun firing a projectile at a lower velocity.

The tendency to-day is to dispense with nickel and to use ordinary steel, "harveyed";[1] this gives excellent 6-inch plates, but there is some difference of opinion as to whether it is advantageous to omit nickel in the case of very thick plates, and the problem is now being worked out by the method of trial. Probably, too, the harveyed plates will be much improved by judicious forging after the process, as indicated by some recent work done in America. The use of chromium in the plates may lead to interesting results.

Turn for a moment to the *Majestic* class of ships, the construction of which we owe to the genuis of Sir William White, to whom I am indebted for a section representing the exact size of the protection afforded to the barbette of the *Majestic*. [This section was exhibited and is shown as reduced to the diagram, fig. 2, Pl. XXVI.] Her armor is of the harveyed steel, which has hitherto proved singularly resisting to chromium projectiles.

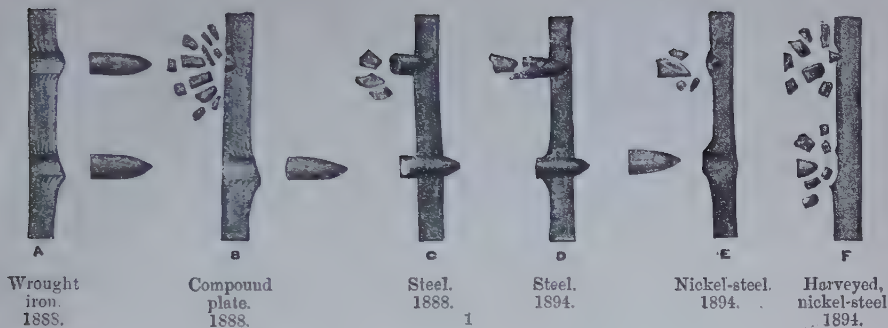
In this section A represents a 14 inch harveyed steel armor plate, B a 4-inch teak backing, C a 1¼-inch steel plate, D ½-inch steel frames, and E ½-inch steel linings.

It will, I trust, have been evident that two of the rarer metals, chromium in the projectiles and nickel in the armor, are playing a very important part in our national defenses; and if I ever lecture to you again, it may be possible for me to record similar triumphs for molybdenum, titanium, vanadium, and others of these still rarer metals.

Here is another alloy, for which I am indebted to Mr. Hadfield. It is iron alloyed with 25 per cent of nickel, and Hopkinson has shown that its density is permanently reduced by 2 per cent by an exposure to a temperature of $-30°$ that is, the metal expands at this temperature.

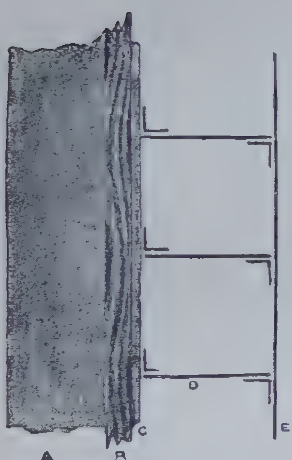
Supposing, therefore, that a ship of war was built in our climate of ordinary steel and clad with some 3,000 tons of such nickel-steel armor, we are confronted with the extraordinary fact that if such a ship visited the arctic regions it would actually become some 2 feet longer and the shearing which would result from the expansion of the armor by exposure to cold would destroy the ship. Before I leave the question of the nickel iron alloys let me direct your attention to this triple alloy of iron, nickel, and cobalt in simple atomic proportions. Dr. Oliver Lodge believes that this alloy will be found to possess very

[1] Engineering, Vol. LVII. 1894, pages 465, 530, 595.



1

ATTACK OF 6-INCH ARMOR PLATES BY 4.72-INCH SHELLS, WEIGHING 57.2 POUNDS.



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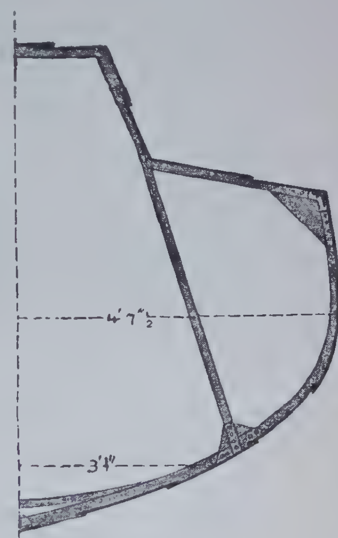

3

4

RARER METALS AND THEIR ALLOYS.

1. The upper series of projectiles are Palliser chilled-iron shells, and the lower are chrome steel. In each case the velocity of the projectile is approximately 1,640 foot-seconds and the energy 1,070 foot tons.
2. Section of barbette of the *Majestic*.
3. Half section midship of aluminum torpedo boat.
4. Preparations for the microscope of diamonds and other forms of carbon obtained from carburized iron.

remarkable properties; in fact, as he told me, if nature had properly understood Mendeléef this alloy would really have been an element. As regards the electrical properties of alloys, it is impossible to say what services the rarer metals may not render; and I would remind you that "platinoid," mainly a nickel-copper alloy, owes to the presence of a little tungsten its peculiar property of having a high electrical resistance which does not change with temperature.

One other instance of the kind of influence the rarer metals may be expected to exert is all that time will permit me to give you. It relates to their influence on aluminum itself. You have heard much of the adoption of aluminum in such branches of naval construction as demand lightness and portability. During last autumn Messrs. Yarrow completed a torpedo boat which was built of aluminum alloyed with 6 per cent of copper. Her hull is 50 per cent lighter and she is $3\frac{1}{2}$ knots faster than a similar boat of steel would have been, and, notwithstanding her increased speed, is singularly free from vibration.

Her plates are one-tenth of an inch thick and one-sixth of an inch where greater strength is needed. It remains to be seen whether copper is the best metal to alloy with aluminum. Several of the rarer metals have already been tried, and among them titanium. Two per cent of this rare metal seems to confer remarkable properties on aluminum, and it should do so according to the views I have expressed, for the cooling curve of the titanium-aluminum alloy would certainly show a high subordinate freezing point. (Fig. 3, Pl. XXVI.)

Hitherto I have appealed to industrial work rather than to abstract science for illustrations of the services which the rarer metals may render. One reason for this is that at present we have but little knowledge of some of the rarer metals apart from their association with carbon. The metals yielded by treatment of oxides in the electric arc are always carburized. There are, in fact, some of the rarer metals which we as yet can hardly be said to know except as carbides. As the following experiment is the last of the series, I would express my thanks to my assistant, Mr. Stansfield, for the great care he has bestowed in order to insure their success. Here is the carbide of calcium which is produced by heating lime and carbon in the electric arc. It possesses great chemical activity, for if it is placed in water the calcium seizes the oxygen of the water, while the carbon also combines with the hydrogen, and acetylene is the result, which burns brilliantly. [Experiment shown.] If the carbide of calcium be placed in chlorine water evil-smelling chloride of carbon is formed.

In studying the relations of the rarer metals to iron it is impossible to dissociate them from the influence exerted by the simultaneous presence of carbon; but carbon is a protean element—it may be dissolved in iron, or it may exist in iron in any of the varied forms in which we know it when it is free. Matthiessen, the great authority on alloys, actually writes of the "carbon-iron alloys." I do not hesitate,

therefore, on the ground that the subject might appear to be without the limits of the title of his lecture, to point to one other result which has been achieved by M. Moissan. Here is a fragment of pig iron highly carburized; melt it in the electric arc in the presence of carbon and cool the molten metal suddenly, preferably by plunging it into molten lead. Cast iron expands on solidification, and the little mass will become solid at its surface and will contract; but when, in turn, the still fluid mass in the interior cools it expands against the solid crust, and consequently solidifies under great pressure. Dissolve such a mass of carburized iron in nitric acid to which chlorate of potash is added; treat the residue with caustic potash, submit it to the prolonged attack of hydrofluoric acid, then to boiling sulphuric acid, and finally fuse it with potash to remove any traces of carbide of silicon, and you have carbon left, but in the form of diamonds.

If you will not expect to see too much I will show you some diamonds I have prepared by strictly following the directions of M. Moissan. As he points out, these diamonds, being produced under stress, are not entirely without action on polarized light, and they have sometimes the singular property of flying to pieces like Rupert's drops when they are mounted as preparations for the microscope. [The images of many small specimens were projected on the screen from the microscope, and fig. 4, E, Pl. XXVI, shows a sketch of one of these. The largest diamond yet produced by M. Moissan is 0.5 millimeter in diameter.]

A (fig. 4, Pl. XXVI) represents the rounded, pitted surface of a diamond, and B a crystal of diamond from the series prepared by M. Moissan, drawings of which illustrate his paper.[1] The rest of the specimens, C to F, were obtained by myself by the aid of his method as above described. C represents a dendritic growth apparently composed of hexagonal plates of graphite, while D is a specimen of much interest, as it appears to be a hollow sphere of graphitic carbon, partially crushed in. Such examples are very numerous, and their surfaces are covered with minute round graphitic pits and prominences of great brilliancy. Specimen E (which, as already stated, was one of a series shown to the audience) is a broken crystal, probably a tetrahedron, and is the best crystallized specimen of diamond I have as yet succeeded in preparing. Minute diamonds, similar to A, may be readily produced, and brilliant fragments, with the lamellar structure shown in F, are also often met with.

The close association of the rarer metals and carbon and their intimate relations with carbon, when they are hidden with it in iron, enabled me to refer to the production of the diamond, and afford a basis for the few observations I would offer in conclusion. These relate to the singular attitude toward metallurgical research maintained by those who are in a position to promote the advancement of science in this country. Statements respecting the change of shining graphite

[1] Comptes Rendus, Vol. CXVIII, 1894, page 324.

into brilliant diamond are received with appreciative interest; but, on the other hand, the vast importance of effecting similar molecular changes in metals is ignored.

We may acknowledge that "no nation of modern times has done so much practical work in the world as ourselves, none has applied itself so conspicuously or with such conspicuous success to the indefatigable pursuit of all those branches of human knowledge which give to man his mastery over matter."[1] But it is typical of our peculiar British method of advance to dismiss all metallurgical questions as "industrial," and leave their consideration to private enterprise.

We are fortunately to spend, I believe, eighteen millions this year on our navy, and yet the nation only endows experimental research in all branches of science with £4,000. We rightly and gladly spend a million on the *Magnificent*, and then stand by while manufacturers compete for the privilege of providing her with the armor plate which is to save her from disablement or destruction. We as a nation are fully holding our own in metallurgical progress, but we might be doing so much more. Why are so few workers studying the rarer metals and their alloys? Why is the crucible so often abandoned for the test tube? Is not the investigation of the properties of alloys precious for its own sake, or is our faith in the fruitfulness of the results of metallurgical investigation so weak that, in its case, the substance of things hoped for remains unsought for and unseen in the depths of obscurity in which the metals are left?

We must go back to the traditions of Faraday, who was the first to investigate the influence of the rarer metals upon iron, and to prepare the nickel-iron series of which so much has since been heard.[2] He did not despise research which might possibly tend to useful results, but joyously records his satisfaction at the fact that a generous gift from Wollaston of certain of the "scarce and more valuable metals" enabled him to transfer his experiments from the laboratory in Albemarle street to the works of a manufacturer at Sheffield.

Faraday not only began the research I am pleading for to-night, but he gave us the germ of the dynamo, by the aid of which, as we have seen, the rarer metals may be isolated. If it is a source of national pride that research should be endowed apart from the national expenditure, let us, while remembering our responsibilities, rest in the hope that metallurgy will be well represented in the laboratory which private munificence is to place side by side with our historic Royal Institution.

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[1]The Times, February 22, 1895.

[2]In the development of the use of these alloys the Société Ferro-Nickel and Les Usines du Creuzot deserve special mention.

PRELIMINARY ACCOUNT OF AN EXPEDITION TO THE PUEBLO RUINS NEAR WINSLOW, ARIZONA, IN 1896.[1]

By J. WALTER FEWKES.

ITINERARY, PERSONNEL, AND COLLECTIONS OF THE EXPEDITION.

The archaeological expedition under my charge, sent out by the Bureau of American Ethnology of the Smithsonian Institution, in the summer of 1896, began work at Winslow, Arizona, on June 2nd. An exploration was first made of a ruin called by the Hopi Indians Homolobi, situated 3 miles from that town, near Sunset Crossing of the Colorado Chiquito River. I discovered a second ruin 3 miles north of Homolobi, on the same side of the river, and on the left bank a small cluster of houses about 4 miles from Winslow, near the site of a Mormon town (now abandoned) called Brigham City. I likewise visited a fourth ruined pueblo 6 miles from the railroad, on the left bank of the Colorado, north of Winslow.

At the close of June the seat of explorations was moved to a ruin near Hardy, Arizona, about 15 miles east of Winslow, on the left bank of Chevlon Creek near where it empties into the Colorado Chiquito. Having made extensive excavations at that ruin, we went to Chaves Pass, between 30 and 40 miles about southwest of Winslow, closing the month of July at that place. Shipping the collection which had been obtained from these three ruins to Washington at the close of July, we went to the Middle Mesa of Tusayan, where we arrived on the 3d of August, and immediately began work at the ruin of Old Cuñopavi. At the earnest entreaty of Nacihiptewa, chief of the pueblo Cuñopavi, my work on the cemetery of Old Cuñopavi was given up at the end of two days. We then moved to Walpi, prospected the ancient site of that pueblo, called Kisakobi, with a view to renewed exploration. I also made a reconnaissance in a reported prehistoric home of the Katcina people, called Katcinaba, situated about 3 miles from Sikyatki, but for various reasons we were led to abandon archaeological work for the summer with the experiences at Cuñopavi. We therefore set ourselves to the solution of certain ethnological problems, and the collection of

[1] Preliminary account, prepared and transmitted in December, 1896.

material illustrating obscure points of modern Hopi life. I attended the Flute ceremonies[1] at Walpi and Micoñinovi, saw the Snake dances at Oraibi, Cuñopavi, and Cipaulovi, which had never been witnessed by ethnologists, and left Tusayan at the close of August.

After visiting Zuñi we went to Isleta and Sandia, made a trip to Tesuki, and returned to Washington September 23rd.

I was accompanied, during my explorations, by Dr. Walter Hough of the National Museum, to whose valuable aid much of the success of the expedition is due.

It was advantageous to hire for laborers both Mexicans and Moki Indians, but the latter only were employed on the reservation, for obvious reason. While unaccustomed to hard labor, and physically unable to do as much in a day as a white man, the Indians were faithful laborers, and the young men, especially those from the East Mesa, are anxious for employment, not lazy, but willing to do their best.

I found Mr. Peter Stauffer, formerly industrial teacher in the Moki School, exceptionally well fitted for camp duties; and to the energy of Mr. J. Bargeman is due the great amount of manual work accomplished by excavations.

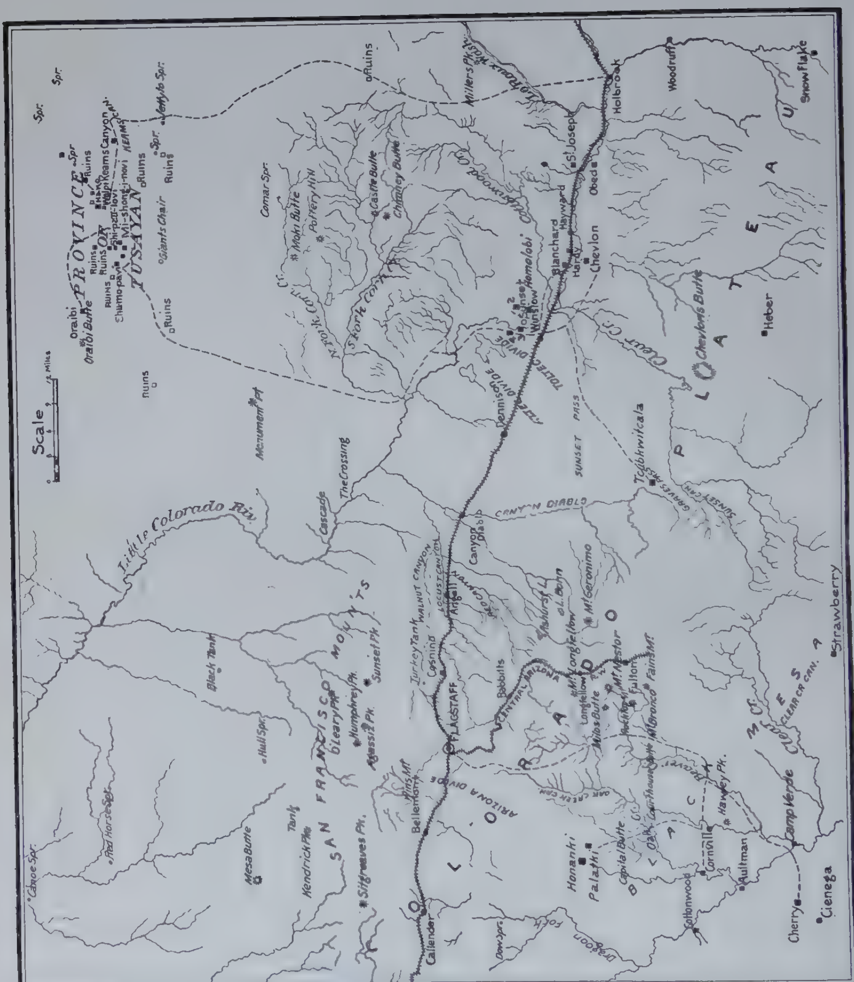
An exact enumeration of the specimens collected is not possible at this time, but my field catalogue has over 1,700 entries, in addition to which there are fully 500 more objects. Probably the whole number of specimens added to the Museum by the expedition of 1896 will not fall far short of 2,500 objects.

The nature of this varied material is both ethnological and archaeological, the latter, of course, largely predominating. The ethnological specimens were gathered from Walpi, Zuñi, Isleta, Sandia, and Tesuki. Among these may be mentioned a number of objects purchased at Santa Fé, illustrating the condition of the missions of the Rio Grande Pueblos in the seventeenth and eighteenth centuries. This collection includes paintings on buffalo and other skins, mural ornaments, crosses, and the like. Although small, when added to the few already in the Museum they make a fair beginning of a collection illustrating the mutual influence of aboriginal and Christian art among the Pueblos. Noteworthy among these specimens is a painting on skin, from the walls of an old mission, in which the figure of a saint is represented in a cloud from which descends parallel lines symbolic of falling rain, and a picture of the Crucifixion on a slab of wood, the edge of which is cut in the form of a terraced rain cloud.

Dr. Hough, at my suggestion, collected a considerable herbarium, illustrating Hopi medicinal and alimentary plants, obtaining their aboriginal names and uses.[2] He likewise made a collection of fossils

[1] The observations which were made have been published in an article entitled, "The Micoñinovi Flute Altars," Journ. Amer. Folk Lore, 1896.

[2] The results have been published in an article entitled, "The Hopi in Relation to their Plant Environment." Amer. Anth., Feb., 1897.



Map of Eastern-Central Arizona.
(Itinerary indicated by dotted lines.)

from the formation underlying the Middle Mesa of Tusayan, which will, it is hoped, shed light on obscure points in Tusayan geology.

The archæological material consists of a large collection of prehistoric pottery of many different forms, colors, and degrees of excellence, stone implements, basket ware, cloth, jewelry, pigments, and sacred paraphernalia, the majority of which are of a mortuary character.

The series of skulls which were collected numbers eighty, which is the largest assemblage of somatological material ever made from the ruined pueblos of the Colorado Chiquito. The close resemblance between the skulls of the ancient Cibolans and those of the accolents of the Gila-Salado has been commented on by others.[1] The modern Hopi, however, approach more closely to the former inhabitants of the Gila Valley in their craniometric features than do the modern Zuñis. The large collection of skulls from Chaves Pass affords abundant material for the solution of an important question, and when properly "worked up" will shed light on the relationship of the Pueblos to the Gila and Salt River tribes.

We recognized that it would be instructive, in view of the agricultural life of prehistoric Pueblos, to know something of the animals, domestic and otherwise, by which the ancients were surrounded, or those which they hunted and used for food. For the purpose of answering this question we carefully gathered all bones of animals found in excavating the rooms of Homolobi, especially those associated with undoubted prehistoric material. This unique collection grew to considerable size, and will furnish material for a special article.

In addition to objects I collected abundant notes, photographs, and drawings, gathering data for elaboration into special articles. I have been able to fill several gaps in my knowledge of the intricate Tusayan ritual, especially the secret rites of the Snake dances at Cipaulovi, Oraibi, and Cuñopavi.[2]

SCOPE AND AIM OF THE EXPLORATION.

The primary object of my expedition was a collection of prehistoric material from our Southwest, and in pursuit of this end I was able to continue the lines of investigation inaugurated in the summer of 1895. I am attempting to follow an archæological base line from the inhabited pueblos of Tusayan to the ruins of the Gila and Salado watershed. Broadly considered, the goal before me is to determine the origin of the southern component of the Moki Indians, and the special aspect of that problem, which I considered in the summer of 1896, was to investigate by archæological methods the claim of the Patki family that their ancestors lived near Winslow and at Chaves Pass.

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[1] Journ. Amer. Eth. and Arch., Vol. III., No. 2.

[2] This material was published in the Sixteenth Annual Report of the Bureau of American Ethnology.

The ruined pueblos near Winslow are called by the traditionalists best versed in the story of the migration of the Patki family by the name Homolobi. Unfortunately, no known object of aboriginal manufacture had ever been obtained from this vicinity by the archæologist, and on my arrival at the town I found little encouragement that I should be any more successful, for no one there knew of any ruins in the neighborhood of the town save those of the Mormon settlements, Brigham and Sunset City. A few days' explorations, however, showed that Winslow is one of the best points for archæological studies in the pueblo area. By the aid of Hopi workmen we discovered Homolobi, from which were taken several hundred most beautiful objects of prehistoric handiwork. Having, as I believe, successfully demonstrated that the legend that the Patki or some other Moki family formerly lived near where Winslow now stands was true, it was desirable to extend explorations still farther south. Although this family once lived at Homolobi, that pueblo was only one of their homes in their northern migration. Earlier in their history, it is claimed, they came from far to the south. The ruins of former halting places must be searched for in this direction. I had in this quest also traditions to guide me, even the trail indicated. In the old times, up to the present generation, in their trading visits to the Pimas the Hopi took the trail through Chaves Pass, an available one for them to cross the rugged malpais of the Mogollones. I followed this trail from Homolobi to the pass and examined ruins which had been reported, studying their evidence of Hopi kinship. The results confirmed traditions, and will be developed later in this report.

The ruin at Chevlon was excavated with the hope of adding new data to aid in an intelligent interpretation of the resemblances between ancient Hopi and Zuñi cultures, which are regarded as practically identical. It had long been my belief that the differentiation of Tusayan, Zuñian, Keresan, and Tanoan aspects of pueblo cultures is of modern origin, and that in no very ancient times resemblances between them were greater than to-day. Manifestly this question can not be properly answered save by a knowledge of objects from ancient ruins. The ruin at Chevlon is situated about the same distance from Zuñi pueblo as from Walpi, and its former inhabitants might easily be related to the ancestors of both. The Hopi claim it as a home of their forefathers, and it should not be regarded as strange if the Zuñis do the same, for indeed both may be right. The ancestors of both were intimately related in their culture; but we can not tell how close the ancient Hopi were to the ancient Zuñi until we know something definite about both.[1]

As a rule, the ancient ruined pueblos of the valley of the Little Colorado were built of stone, while those of the Gila-Salado drainage

[1] There is a closer resemblance between prehistoric objects from the Chevlon ruins and Zuñian antiquities than between the former and Tusayan, but our knowledge of the old Zuñi ruins is as yet very imperfect.

area were of stone and clay; stone was used in the upper part of the river and its tributaries, and pressed clay in the great plains of the lower Gila-Salado. The ruins of the Verde Valley, the natural pathway between these two regions, are of stone. I have elsewhere claimed that the character of aboriginal pueblo buildings in our Southwest is determined by the geological environment. It would give strength to the argument could we find instances where the same people who in rocky places built homes of stone constructed clay houses in plains where stone failed. Between Homolobi and modern Tusayan, following the Little Colorado, the river winds through level plains where stones for building material fail, the nearest rocks being several miles from the river banks. Following the right bank of the stream for some distance on my way from Homolobi to Tusayan, we narrowly scanned every evidence of former aboriginal occupation for evidences of ruined buildings of adobe. At several points there were mounds of ancient pueblos in which no stone was used in the construction of the walls, although they were thickly strewn with fragments of pottery. It will probably be found that there were several small adobe pueblos along the banks of the Colorado between Homolobi and the Crossing, wherever the valley broadens into a plain.

With this general sketch of the scope of my work, let us pass to a special consideration of the four ruins, Homolobi, Cakwabaiyaki, Tcübkwitcalobi,[1] and Old Cuñopavi, which were studied by my party. The first three are far south of the Moki Reservation, although ancestrally situated in Tusayan. Roughly speaking, the pueblo at Chaves Pass was about halfway between the Moki town, Walpi, and the great buildings near Tempe and Phœnix. The distance of the Chevlon ruin from Zuñi is about the same as from Walpi.

HOMOLOBI.

There are no less than four extensive ruins within 6 miles of Winslow, Arizona, near to or remote from the banks of the Little Colorado. All of these are claimed by the Hopi as dwelling places of their ancestors. The nearest, and that especially studied, is 3 miles away and was a pueblo of considerable size, situated on the plain of the right bank of the river, which has in freshets overflowed its banks and washed away a portion of the walls. It is separated from the present right bank of the stream by a level river bottom, in which now grow stunted cottonwoods and other trees.

The mounds of this ruin exhibited no evidences, when we began work, of rooms above ground, although I was told that in comparatively recent times it had walls rising to a considerable height, and that the Mormons,

[1] The names chosen to designate the ruins at the Chevlon and Chaves Pass are of Hopi etymology, but not necessarily the only ones applied by them to these ancient pueblos. Cakwabaiya is a name applied to Chevlon Creek, and Tcübkwitcala, Antelope Notch, to Chaves Pass.

in building Sunset City, a mile away, but now in ruins, utilized the stones from this ruin for their buildings. Although the walls above ground have been wholly destroyed, the ash-colored mounds indicating the ruin are readily seen from a considerable distance. The original pueblo appears to have been of rectangular shape, with inclosed plazas overlooked by more than single-storied rooms on the east side.

The second ruin, which is referred to the Homolobi group, lies about 3 miles beyond the first and on the same side of the river, but is separated some distance from its right bank. This pueblo is much larger than either of the others and crowns a high mesa. The walls of the rectangular rooms are still clearly discernible above the surface of the ground, and in some places even wooden beams are still in place. This ruin would well repay excavations, but its distance from water deterred me from undertaking them, and other advantages presented by the former ruin so far outweighed those connected with this that I attempted only a day's work at this place.

A third ruin of the Homolobi group is situated on the left bank of the river, just beyond the site of old Brigham City. The periodically swollen Colorado had washed into this ruin and worn away a considerable section along the river front. The character of the ruin indicates that it was a small pueblo built in part of blocks of adobe, and possibly abandoned on account of the encroachment of the stream, although well situated for farming the adjacent valley.

The fourth ruin is perched on top of a mesa at about an equal distance from Winslow as the second, but on the left or opposite bank of the river. The pueblo covered almost the entire top of a conical butte, which on one side is almost inaccessible. This ruin indicates a village of considerable size, as shown by the fallen débris and abundance of pottery fragments strewn on the talus at the base of the cliffs. The pictographs on bowlders half way up the hill following an old trail are abundant, characteristic, and well preserved.

My knowledge of the character of prehistoric culture at Homolobi is drawn mainly from facts obtained at the first ruin, but the similarities of all four ruins implies an intimate connection and a close likeness in the manners and customs of their inhabitants. For convenience it may be best to designate the group of ancient towns about Winslow as the Homolobi group, but I will not commit myself to the statement that they were all simultaneously inhabited. There is as yet, however, no evidence that they were not, and every probability that the time of abandonment[1] of all was not far apart.

Although past experience had shown me that excavations in the rooms of ruins reveal few specimens of value, as compared with those in cemeteries, I made extensive excavations of the rooms of Homolobi to determine their form, the number of stories, and their distribution

[1] The reason for their desertion is variously stated to have been inroads of hostile bands, failure of crops, swarms of insects, etc.

VASE WITH FOUR BIRDS.
(Homolobi, No. 156676.)

BIRD DESIGN.
(Food bowl, Homolobi, No. 156603.)

in the mounds. These excavations showed that the majority of the rooms were large, that their walls were nicely plastered, and that they were two stories high in some places. In more than one part of the ruin we came upon well preserved cedar beams of flooring several feet below the surface. Fireplaces (?) and windows were found, but only rarely, although passages from one chamber to another were common. In one of the rooms we found a human skeleton, apparently of an old man, but with no evidences of careful burial. The skull of an infant lay on the floor of another room. It was interesting likewise to note that in the large flat slabs on the floor of one of the larger chambers we found small round holes, carefully made, which suggested the sipapù, or symbolic opening, the orifice through which, it is held, races originally emerged from the underworld. As this is one of the features in the kiva floors at Tusayan, we might readily consider the chamber in question to have been a sacred room or kiva; but later in our excavations we found many similar slabs of perforated stone near graves in the necropolis, which suggests that possibly these stones were used in the floors of rooms to cover the dead in intramural interments.

The great collections of prehistoric objects which were taken at Homolobi came from the necropolis, or burial place, which is always the most wonderful in its revelation of the character of ancient life. The cemeteries of Homolobi were situated, just outside the town, in the slope of the mound, only a few feet from the outer wall. The dead were thus practically interred in the very shade of the pueblo, and were not carried to any distance. There was nothing superficially visible to indicate these interments, save now and then the edge of a flagstone placed upright in the soil. The custom of intramural burial and interment just outside the house walls seems to have been of very ancient date; the transportation of the deceased to a distance, more modern. Pueblos, like Awatobi and Old Cuñopavi, which were under Spanish influence, practiced both methods, but the inhabitants of the present inhabited or modern Tusayan pueblos long ago abandoned burials in their villages, and now carry their dead down the mesa, or some distance from the town. At Sikyatki the cemeteries were a few hundred feet distant from the pueblo, while at Homolobi, Chevlon, and Chaves Pass the dead were buried in the town, or close outside the walls. I found no evidence of cremation of the dead.[1] Almost every grave was indicated by a flat stone slab, which stood upright or lay above a skeleton. Some of these stones were perforated with round, oval, or square holes. There was no uniformity in the orientation or positions of the dead, for some of the bodies were extended, others had knees drawn to the breast, and still others were lying on one side. Double and multiple burials were

[1] Although it is distinctly stated by early Spanish writers that the Cibolans burned their dead, the finding of skeletons in ancient Zuñi ruins shows that the ancient Zuñians did not always cremate. The great numbers of skeletons found in and about the ruins of the Little Colorado indicates that burial in the ground was a general custom.

common. The place of interment extended from the northeast to the southeast angles of the ruin, and the average depth of burial was about five feet below the surface of the ground. Very shallow graves were also common, but the deeper we excavated the better preserved were the mortuary objects, the finest pottery being found at the lowest depth.

There appeared to have been no consecration of the soil in which the dead were once interred, and the same burial ground was apparently used several times, after intervals of time. The habit of placing mortuary votive offerings was almost universal, and almost every grave excavated contained one or more objects of pottery,[1] stone implements, ceremonial paraphernalia, and the like. The perishable food material formerly deposited in the bowls was, as a rule, so much destroyed that no opinion can be expressed in regard to its character. Valuable ornaments were left on the bodies of the dead.

The pottery from Homolobi differs in color from the true Cuñopavi and Sikyatki wares, but contains a considerable number of bowls, vases, and jars of similar form. Roughly speaking, about one-third of the specimens from Homolobi are similar in color with those from Sikyatki; another third, red and black ware, which is glazed, and the remainder, white and black, like the cliff-home pottery. These differences in color are, I believe, mainly due to the kind of clays, pigments, and other components used in their manufacture, but the symbolism of all wares, however colored, is practically identical.

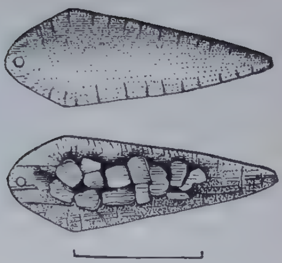
The large number of vessels belonging to the red and black, and black and white varieties, identical with those sometimes said to be characteristic of the cliff dwellers, lead me to the conclusion that the ancient pueblo villages made the same kind of pottery, and adorned it in the same way, whether they lived in cliff houses or in villages in the the plain.[2] This conclusion could not have been demonstrated without extensive excavations in pueblo ruins, such as the means at my disposal made possible in the Homolobi region.

Vases, as a rule, are ornamented on the exterior, and I have but a single specimen decorated on the interior. This figure represents on one side of the rim the head, breast, and arms of a human being, holding in outstretched hands rattles or spears. Below this figure there are, in the interior of the bowl, two footprints, as if from one who had leaped into the jar. From these two footprints a line of steps extends across the interior of the jar, ending on the diametrically opposite rim, behind a figure of the lower body and legs of a man crawling out of the bowl on the opposite side. This internal decoration is unique, and undoubtedly had an important meaning in the mind of the delineator.

The pictographic decorations of Homolobi pottery which can be identified are few in number compared with those from Sikyatki, which

[1] While much pottery was broken, many pieces were entire.

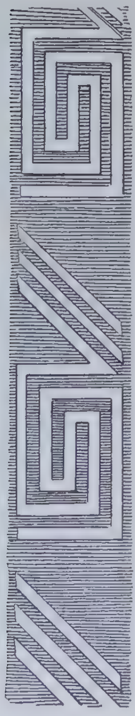
[2] In other words, while black and white ware is among the most abundant kinds in cliff houses, it is not characteristic of or confined to them, thus indicating contemporaneity of occupation.



BONE EAR PENDANTS.
(Chevlon, No. 157852.)

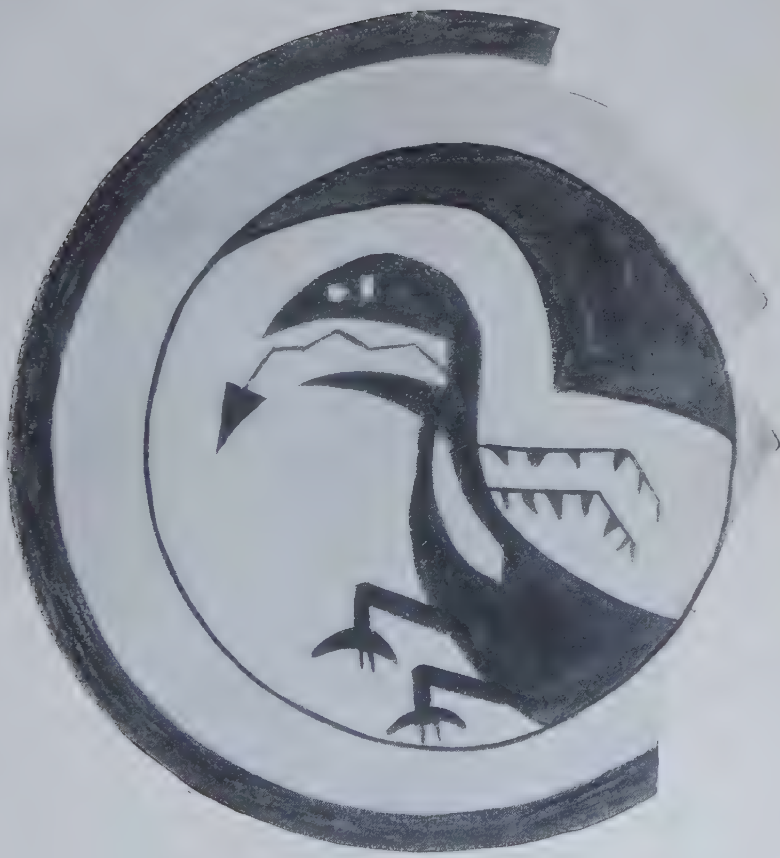
COPPER BELL.
(Chaves Pass, No. 157839.)

FOOTPRINTS ON INSIDE OF A VASE.
(Homolobi, No. 156690.)

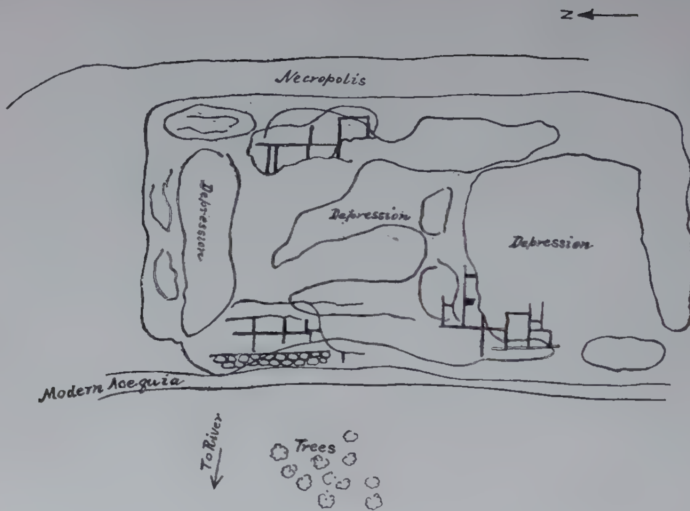


BROKEN FRET.
(Food bowl, Chevlon, No. 157895.)

DIPPER.
(Homolobi, No. 156891.)



BIRD FIGURE.
(Food bowl, Homolobi, No. 156870.)



PLAN OF HOMOLOBI.

MYTHIC SPIDER AND SUN EMBLEM.
(Food bowl, Homolobi, No. 156888.)

is, I believe, a highly significant fact. The figures of birds predominate, but these differ essentially from those represented in the paleography of Cuñopavi and Sikyatki. As a rule, they are crude in form and less artistically made, a generalization which is likewise true of the ceramic ware as a whole, looking at it either from the point of view of finish or ornamentation. The ancient pottery from Sikyatki and old Cuñopavi is superior to any which I have examined from the Southwest. That from the Homolobi region is cruder, more like ancient Zuñi ware, indicating a less developed artistic taste and pointing to but not proving a high development of culture in prehistoric Tusayan. As we compare articles from the Chevlon ruin with those from Zuñi we find close likenesses,[1] but if anything the ancient Cibolan ware is inferior to that of Homolobi, both of which is greatly inferior to the ancient Tusayan pottery.

The only instance in which I have found a figure of the spider in pottery from prehistoric ruins of the Southwest was on a food basin, the interior of which was adorned with a representation of this animal. It had the four pairs of legs characteristic of Arachnida, the globular body, and prominent mandibles of this group. In modern mythology the spider woman is associated with the sun, and it is probable that she is an earth goddess, bride of the sun, called the mother or grandmother of the twin war gods. It is interesting to find on the outer rim of this bowl with spider decoration a figure of the sun similar to that now made yearly by the chief of the Katcinas on the floors of the sacred rooms or kivas in the celebration of the series of ceremonials called the Powamû.[2]

The maize found in the mortuary bowls at Homolobi, and the same is likewise true of the other ruins studied by me, was a small-eared variety, in some instances not more than one or two inches in length. There were many squash seeds, a few cotton seeds, and others not identified.[3]

Among objects of doubtful use found at Homolobi may be mentioned the plastron of a turtle which was cut into a circular form or disk. While we were at work on our excavations at Homolobi a small party of Hopi made a visit to the Chevlon and Clear creeks to collect turtles for use in the sacred dance. They also made prayer offerings, which

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[1] Both the ancient Zuñi pottery and that from lower down the Colorado Chiquito are similar in color, doubtless because of identity in the constituents of the clay and the action of fire upon it.

[2] The modern symbol of the sun which is depicted on the pottery now made in Tusayan is likewise found on the altar screen of the Palülükoñti, or serpent-sun ceremony, and in various other altar paraphernalia. The sun symbol of the Katcinas, however, is slightly different, and that on old pottery resembles the Katcina variant. I suggest that the dual symbol thus recognized can be explained on the theory of diverse origins.

[3] Among the present people in Tusayan, who claim that their ancestors came from the far South, the Squash people were regarded most important. It is held that these people, together with the Sun, Water, and others, once lived on the banks of the Little Colorado. On their advent in Tusayan they settled Tcukubi, a pueblo of the Middle Mesa, now in ruins. The gens is now extinct at Walpi.

they placed in shrines, and carried back water for use in a Katcina dance, the Calako (Sio, Zuñi), which was performed in July[1] in Sitcomovi. These men made a pilgrimage of 80 miles to visit ancestral places of worship. The fact has a significance and is connected with early migrations of cults.[2]

Several sections of the leg bones of some mammalian were found near the skull of one interment. These were possibly hair ornaments.[3]

The second ruin in the Homolobi group which was discovered was situated about 3 miles beyond the first, on the same side of the river, but more distant from its bank. This ruin was a much larger one than that already considered, and crowned the top of a mesa about 200 feet high. The rooms were well marked out by standing walls, and in many instances the remains of wooden beams were still present.

The burial places of this pueblo were in the foothills at the base of the mesa, and the graves were marked by the same rectangular stone slabs recorded in the first ruin. The most instructive food bowl found in these burials was ornamented with the picture of a human being with flowers and butterflies. The chin of the figure is painted black, as is so often the case in idols in Tusayan altars, and faces of participants in dances.[4]

The third ruin[5] was situated on the left bank of the river, not more than 5 miles from the town of Winslow. It was a small village, and so near the stream that the water had washed away one corner of the mounds. I made no excavation at this place, except on one side, but

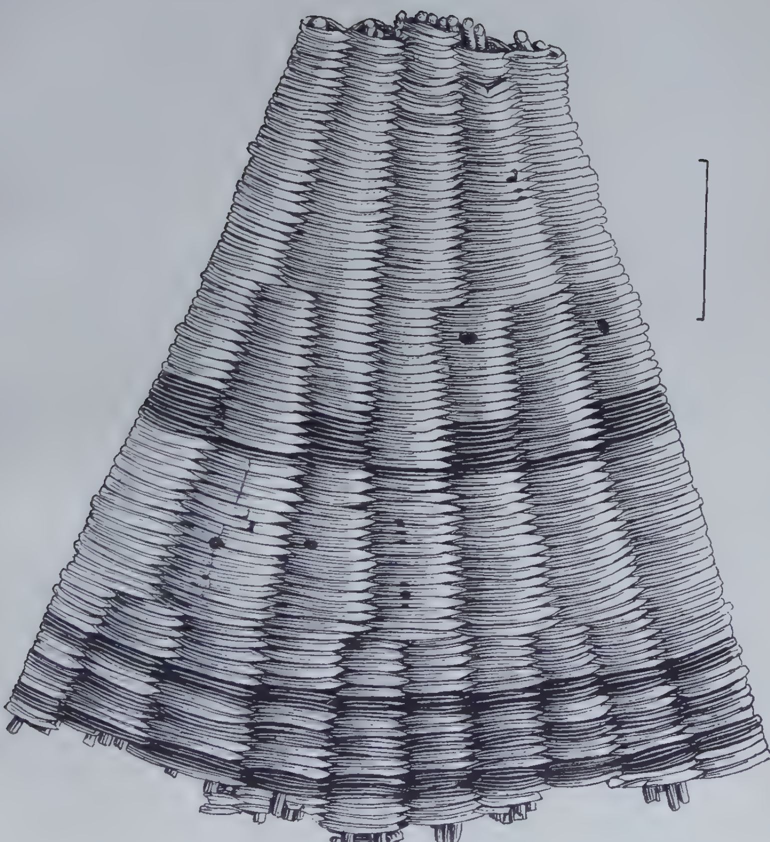
[1] This ceremony has been described in the Fifteenth Annual Report of the Bureau of American Ethnology.

[2] The Sio-Calako was brought to Sitcomovi from Zuñi by several Hopi who had seen it at the latter pueblo not many years ago. As all Katcinas are the special care of the Badger people, the paraphernalia of this ceremony belongs to the Badgers. There are some other Katcinas which were derived from Zuñi, as well as weak representatives of certain priesthoods; but as a rule the Mokis have carefully guarded their peculiar rites, not being willing to sell them even to the Zuñis. About the year 1880 representatives of eleven Zuñi clans visited Walpi and tried to purchase the mysteries of the Snake Dance, but were refused. The Zuñi ritual is not as varied or as rich as the Moki and has suffered more by losses caused by the extinction of ceremonials due to the Spaniards.

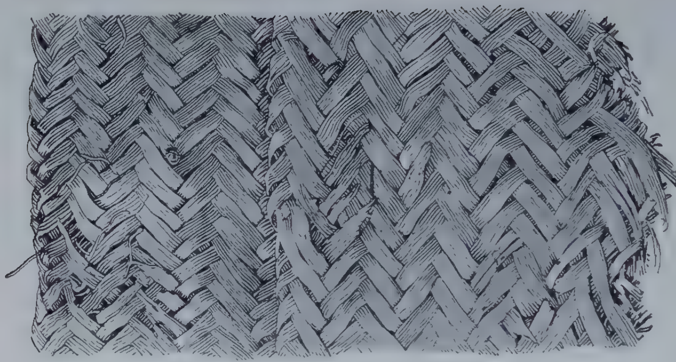
[3] One of the most problematical gentes of the Hopi, which is reputed to have come to Tusayan from the far South, was the "Wiksrun." This gens is said to have been so called because the members of it wore sections of the leg bones of the bear in their hair, hanging down over the forehead. Oñate mentions a people between the Little Colorado and the Great Colorado, called "Cruzados," from their wearing crosses on their foreheads. The Coco Maricopas are said to have worn bone objects in their hair, and this is true of several tribes in the Southwest.

[4] The Antelope priests, Flute girls or Corn maids; see description of the Tusayan Flute Observances.

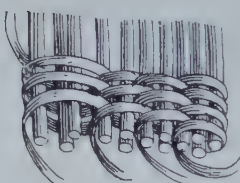
[5] Several clans which were later assimilated with the Tusayan villagers are reported to have built homes along the Colorado Chiquito, and some of the names of these villages are known to Tusayan folklorists. One of these is the old pueblo, Etipsykiya, a home of the Squash people. From the size of some of the ruins along the Little Colorado, I should judge that some of them housed several phratries.

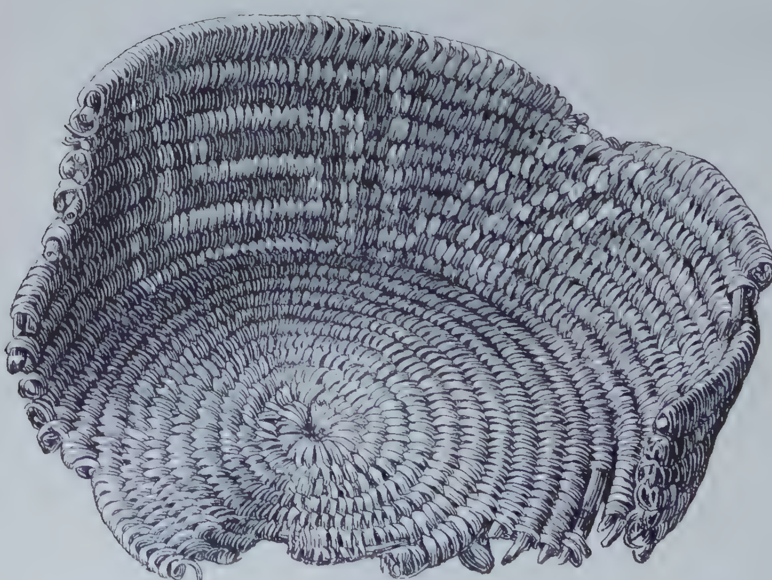


ORAIBI STYLE OF BASKETRY.
(Chevlon, No. 157918.)



MATTING.
(Chevlon, No. 157912.)





ORNAMENTAL BASKETRY, MIDDLE MESA VARIETY.
(Chevlon, No. 157915.)

found that some of the walls were made of adobe blocks as well as stone. Taken in connection with the ruins later found farther down the Colorado, these are the first mention of adobe walls in villages in the Tusayan province, showing, of course, that the builders utilized the most convenient material at hand for their habitations.

The fourth ruin of the Homolobi group was situated on the same side of the river as the last, a few miles farther north. Like the second ruin, it is more distant from the river and crowns a mesa, the walls of which are very steep. This ruin is small and has cemeteries in the débris at the foot of the mesa. The blocks of stone near by were found to be covered with characteristic pictographs[1] made by the modern Hopi.

The second and fourth Homolobi ruins are excellent ones to excavate, and will undoubtedly yield many specimens, although the probability is that objects taken from them will not differ greatly from those which I have brought to Washington from the first ruin.

CHEVLON RUIN.[2]

There are several ruins on Chevlon Creek, one of the most convenient of which to study was that on the left bank near where it flows into the Little Colorado. This ruin, about fifteen miles from Winslow, is in sight of the station Hardy, on the Atlantic and Pacific Railroad, and was the most eastern ruin of those examined.

It is situated on a gravelly hill, nowhere more than a hundred feet high, and in no way different from neighboring hills of the same geological character. No sign of walls were seen above ground, but from a distance the mounds of Chevlon ruin could be readily distinguished by their peculiar light-gray color. The general form of the ruin was rectangular with outlying rows of rooms apparently inclosing a plaza, and the most elevated part was on the northern side.

The cemeteries of this ruin, like those of Homolobi, gave us the majority of objects collected at that place. The pueblo, judging from the contents of the graves, was richer and larger than Homolobi, although there are many likenesses between the two. The portion of the necropolis excavated was situated on the northern side, the graves being found on the slope of the mounds in the immediate vicinity of the outer walls of the town.

The burials were indicated by flat stones, some upright, but mostly horizontal, similar to those of Homolobi. As a rule the bodies were wrapped in a coarse rush matting, which was in many instances well preserved.

Of fragile objects from this ruin may be mentioned fragments of plaited ware, some of which were almost entire baskets. The custom

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[1] Among these were recognized the totem signatures of several clans of the Patki and Squash people, who traditions say once lived in the Colorado Chiquito ruins.

[2] Cakwabaiyaki, Blue Stream pueblo. Higher up or nearer the source of the Chevlon there are other ruins, and in the Clear Creek Canyon several cliff houses.

of burying basket plaques with the dead is still preserved in the Tusayan towns, where it appears to have been inherited from ancient times. Baskets are not now made at the East Mesa of Tusayan, and the craft is confined to the Middle Mesa and Oraibi. The baskets from several graves were identical with those made at Oraibi. There were also representations of the peculiar kind manufactured at Micoñinovi and among the Kohoninos. Some of the baskets were painted on the surface a green or blue[1] color, others had the component twigs stained before they were plaited. When the basket ware was painted the pigment formed a thick coating or layer over the surface.

There was found in a Chevlon grave a large stone slab ornamented in color on both sides. The designs on one side are shown in the accompanying plate, but the figure on the reverse is almost invisible. From the portions still remaining I recognized symbols of the dragon fly. The triangular figure I will not attempt to explain, out of a feeling that it would be presumptuous to attempt it when the best folklorists among the people of Walpi declared that they did not understand its meaning.

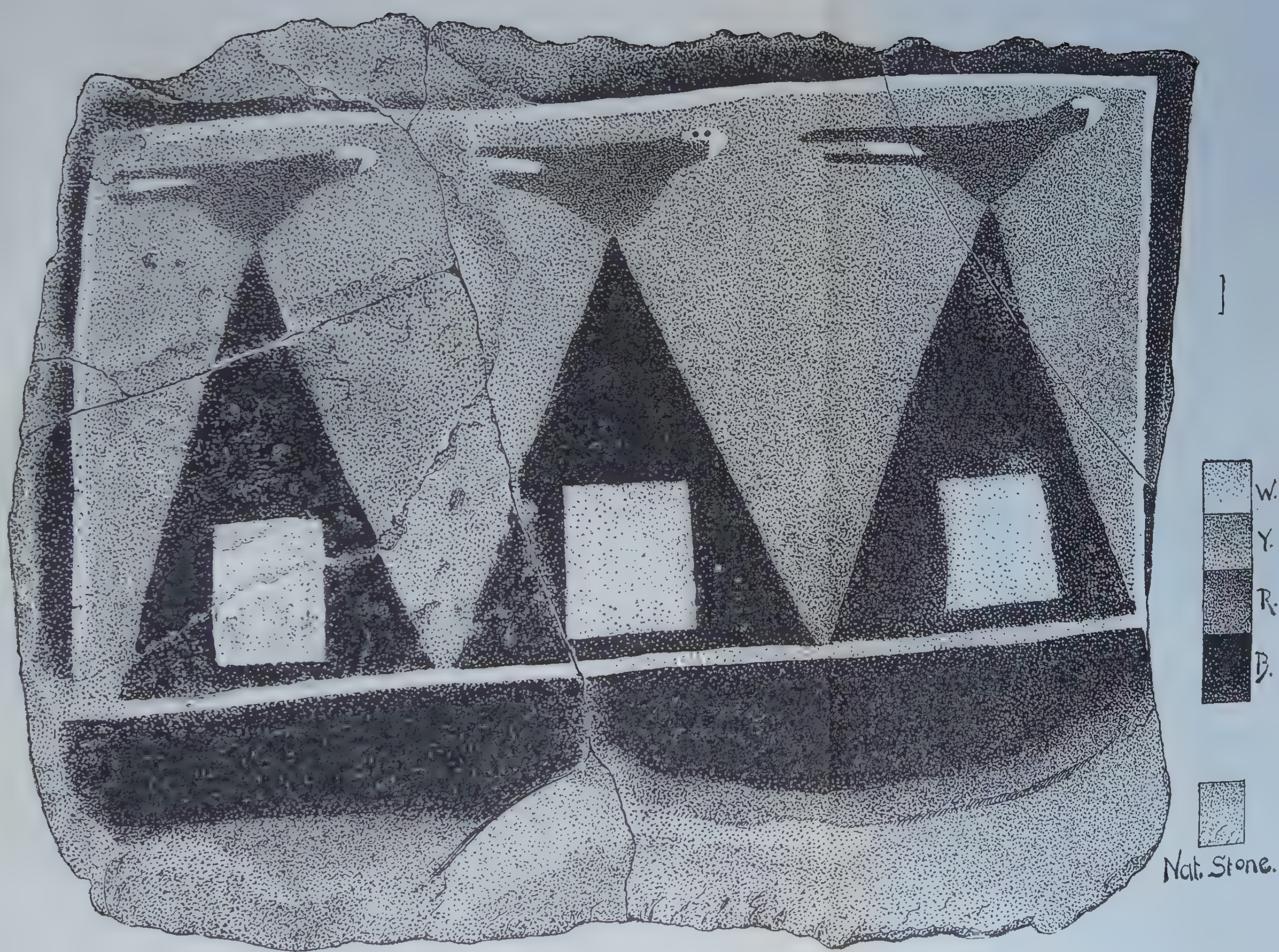
The use of stone, wooden, and burnt clay slabs on the altar of Tusayan priests has been repeatedly illustrated by me in accounts of the Hopi ritual, but none of these bear a symbolism identical with that on the stone slab from a grave in the Chevlon ruin. This form of pictography is therefore exceptional, and the specimen, so far as I know, unique.

The colors with which it was painted are the same as those used to day, and from being mixed with water easily wash off. Undoubtedly this stone slab was used in ceremonials, perhaps prehistoric, and buried in the grave of the priest who performed them, at his demise.

Although the significance of the three triangular figures is unknown to me, their likeness to similar markings on the walls of certain chambers called kivas in the cliff homes of the Mesa Verde is very striking. In the view of the interior of one of these rooms given by Nordenskiöld[2] not only the same number of these triangles are depicted, but also adjacent to one of them, but not on its apex, is represented a bird. It has been suggested that these are rain-cloud symbols, and it may be called to mind that similar figures, reversed, are painted on dados of modern homes, and embroidered on wedding blankets, where they are called butterfly symbols. In the secret rites of the snake dance at Walpi the priests still use a stone slab decorated with a figure of the butterfly or moth, and called the Hokona mana (butterfly virgin).[3]

One of the rarest stone implements found in the Chevlon ruin was an ax of white stone, smoothly polished and symmetrically finished. This implement was ornamented on opposite faces with a simple incised

[1] Blue pigment is azurite; green, carbonate of copper.
[2] Cliff Dwellers of Mesa Verde.
[3] Journ. Amer. Eth. and Arch., Vol. IV.



STONE SLAB WITH RAIN CLOUD AND BIRDS.
(Chevlon, No. 157293.)

Mosaic Frog.

A Hoen & Co., L

cross, and four parallel marks were cut on one edge. The stone was soft, probably limestone, and must have been originally brought to Chevlon from some distance, as similar rock, in place or in fragments, was not found in the vicinity. I have not seen an ax of the same material from any pueblo ruin, but the majority of stone implements are of harder rock. The stone axes from Homolobi are of chipped stone, without groove for hafting.

Several forms of arrow straighteners were found, one of these in the form of a frog. These also served as arrow polishers, and are at the present day used in polishing prayer sticks.

Several stone slabs found in the Chevlon ruin had one surface covered with two rows of blackened circles. They were too heavy for transportation, and my photographs of them were failures. Their use or significance is not known to me.

The occurrence of metates, or grinding stones—flat, worn slabs of rock, on which seeds, probably corn, were ground—in the graves of women indicates a burial custom not without a parallel in modern times. These metates were commonly inverted over the skeleton of the woman at burial. The Indian workmen said that in all instances they indicate the sex of the dead. and, as far as my osteological knowledge goes, it seemed to me that they were right in that statement.

Several objects for personal decoration were taken from the Chevlon ruin, one of the most interesting of which was a large button of polished lignite. A square fragment of the same material, found on a skull near the mastoid process, was inlaid with five small turquoises, one at each angle and one in the middle. This was the only specimen of lignite inlaid with stone which was found, but several specimens of incrusted shell, wood, and bone were taken from the Chevlon ruin. The number of marine shells found in the Colorado Chiquito ruins was very great.[1]

The following have been identified:[2]

Pectunculus giganteus, Reeve.
Melongena patula, Rod. & Sow.
Strombus galeatus, Wood.
Conus Fergusoni, Sow.
Cardium elatum, Sow.
Oliva angulata, Lam.
Oliva hiatula, Gmelin.
Oliva biplicata, Sow.
Turritella tegrina, Keiner.

The most beautiful ornament or fetich of shell incrusted with turquoise was found at the smaller of the two ruins at Chaves Pass. It was a specimen of *Pectunculus giganteus* covered with gum, in which were inlaid rows of turquoises nicely fitted together in the form of a frog or toad. This beautiful object was evidently an ornament, and was taken from the breast of a skeleton buried several feet below the surface in the smaller of the Chaves Pass ruins. As an example of mosaic work this

[1] See Pacific Coast Shells from Prehistoric Tusayan Ruins. Amer. Anth., November, 1896.

[2] For objects made from them, see my article, Amer. Anth., November, 1896.

object is unsurpassed, and with the exception of one other is the only veritable mosaic frog known to me from ruins in the Southwest.[1]

The Chevlon ruin revealed a few specimens of shell carving, one of the best of which was a *Pectunculus* cut in the shape of a frog, with perforations for eyes. Many shell armlets, bracelets, finger rings, and perforated shells of the same species were likewise found. There ought likewise to be mentioned two objects cut out of shell representing, possibly, some animal with head, four legs, and a tail. One of the armlets was beautifully decorated with an incised pattern which is variously modified in color on many prehistoric bowls and jars.

Wood, bone, and shell incrusted with turquoise mosaic were familiar objects to the inhabitants of the Chevlon. One of the most interesting ornaments is a pear-shaped pendant of bone, covered on one surface with a turquoise mosaic. Shell and turquoise were combined in an incrustation on wood in another specimen.

A set of gaming reeds was found in a grave at the Chevlon. These were five in number (four is now the prescribed number), and are similarly marked to those used in gaming at modern Zuñi. This game was, however, known in ancient Tusayan, for we found at old Cuñopavi a beautiful food basin with the same four reeds depicted upon it.

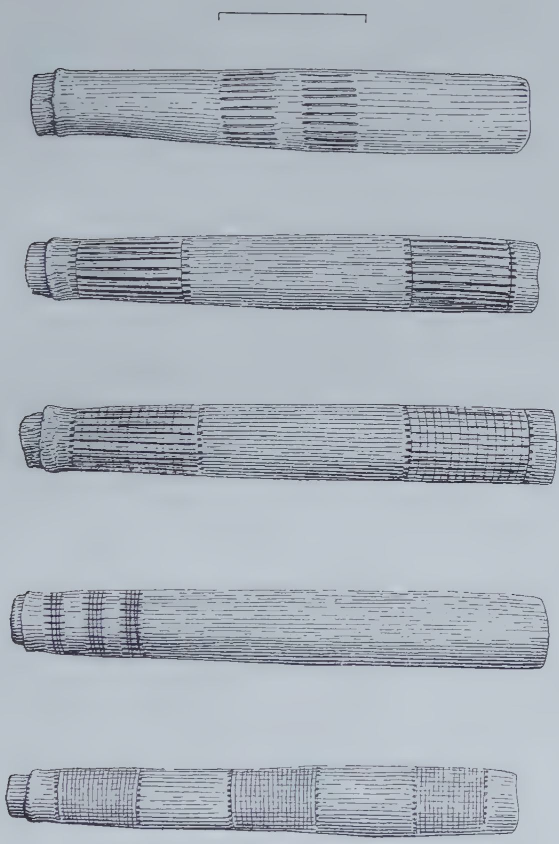
In the same grave with the gaming reeds we found fragments of a bow and arrow which seems to refer the owner to a warrior priesthood.

The pottery from the Chevlon ruin has many resemblances to that of the ancient Zuñi ruins, but is not so fine as that from Sikyatki or Cuñopavi, the old Tusayan pueblos. The predominating colors are different from the latter and similar to those of ancient Cibolan ware, but its decorating designs are mostly geometric figures. As the symbolism of the Chevlon pottery is essentially the same as that of Homolobi, which is undoubtedly Tusayan, and closely akin to that of Cibolan ruins, I am led to the belief that the differences between the old Tusayan towns of the Colorado Chiquito and those of its tributary, the Rio Zuñi, were not very great, and that there was a closer similarity between the ancient Zuñis and Mokis than between the modern pueblos; so that both people may consistently claim kinship with the same ancient people, and their present differences may be interpreted rather as later differentiations than due to dissimilar origins.

Several vessels of clay, painted and fired, made in the forms of animals, were found at the Chevlon ruin. One of these was identified by the Indian workmen as a duck, while others were called birds. One or two of these were so conventionalized that the head, wings, and tail were represented by knobs on the surface of the jar. The most striking of the bird-formed vessels had the form of a macaw or parrot,[2] figures of which bird are constant decorations on many objects of pottery. The

[1] I have, however, seen one or two other specimens which were cleverly made.

[2] The macaw or "gyazro" gens was associated with the Patki, and for obvious reasons came from the South, where the parrot is found.



GAMBLING REEDS.
(Chevlon, No. 158030.)

LAKANA.
(Food bowl, Chaves Pass, No. 157570.)

UNKNOWN QUADRUPED.
(Food bowl, Chevlon, No. 157102.)

MYTHIC BIRDS AND RAIN CLOUD SYMBOLS
(Food bowl, Chevlon, No. 157221.)

JAR WITH FOUR KNOBS.
(Homolobi, No. 156354.)

BIRD SNAKE VASE.
(Chevlon, No. 157311.)

LADLE WITH DIVIDED HANDLE.
(Chevlon, No. 157051.)

LADLE WITH FIGURE ON HANDLE.
(Chevlon, No. 157306.)

wings are represented by parallel lines or feathers, a conventionalism still used on the bodies of Moki dolls.

One of the most suggestive of these jars of animal form is a bird-shaped vessel with folded appendages on each side which suggest legs. It is barely possible that these may be reptilian appendages, in which case the mind naturally recalls the intimate association of the bird and snake, which has been worked out in so clever a way in carvings from Yucatan ruins.

The decoration of rudely coiled or indented pueblo pottery was rarely practiced, but several good specimens were obtained from the ruins of the Little Colorado. This ware is instructive as furnishing a passage from rude ware to highly decorated polished pottery. The accompanying figures show the general character of this kind of ware; it has a peculiarly formed handle, which is nowhere else duplicated. The interior is perfectly polished and black, closely resembling the modern ware of Santa Clara. While this kind of pottery was never extensively manufactured along the Little Colorado, it was not unknown to the people who once dwelt there.

A remarkably fine series of ladles was taken from the graves at the Chevlon ruin, which, while they present no marked peculiarities, are of special interest in the study of the modification in form of their handles. In one specimen the handle is double; in another, decorated with a human figure, and many specimens are ornamented with alternating parallel and cross bars. While the interior of the bowl is generally decorated with geometric patterns, we find the rare abnormality of a figure of a face resembling a Katcina depicted on its surface.

A peculiar kind of ware, so far as I know new to collections of prehistoric pottery from our Southwest, was limited to bowls from the three ruins studied by us last summer. The dominating colors are red, black, and white, the relative amount of the latter predominating. The figures are geometric or stellate, terraced and zigzag forms making up the greater part. Spirals and curved figures are absent. While ware of this kind has been taken only from the area covered by our excavations, its limitation has not been determined. The fact that it is not found at Sikyatki may be explained on the ground that this pueblo was settled by the Kokop or Firewood people, who came not from the south, but from the east, but it is strange that no specimen of it has yet been found in the modern limits of Tusayan.

CHAVES PASS RUINS.

The aboriginal dwellings in Chaves Pass were two in number, one of which was larger than that at Homolobi, which I have already described. These ancient pueblos were situated in the pass on two hills a short distance apart. The country in which they lie is very different from that inhabited by the accolents of the valleys of the Colorado Chiquito.

It is well wooded with beautiful trees, and abundant water, one of the delightful camping places in this part of Arizona. The walls of both ruins were built of lava rocks, and the hills nearby are capped with malpais. From the site of the smaller a wide outlook can be had across the valley of the Little Colorado to the far distant Moki buttes, those great conical elevations of rock which form conspicuous landmarks, for miles about and are in sight of the present Moki villages. The elevation of the ruins at Chaves Pass was considerably higher than that of Homolobi. Chaves Pass from prehistoric times was one of the few available passageways over the Mongollon mountains, and through it ran an old Moki trail, reputed to have been the way used by Hopi traders in visiting the peoples south of the mountains. The tributaries of two watersheds arise from it a few miles away, one flowing into the Little Colorado, the other into the Gila; both eventually into the Gulf of California.

The position of the Chaves Pass ruins is therefore a most important one in discussion of the migration of peoples north and south along these river valleys, and a determination of the culture of the people which inhabited pueblos on such a site is of great importance in a discussion of the ancient home of that component of the Hopi people who claim to have come from the southern region.

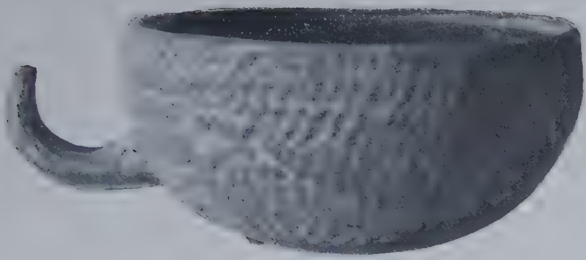
The larger of the two Chaves Pass ruins consisted of two rectangular parts connected by a wall. The highest houses were on the north side, and the rooms of the eastern end were well marked.

Several hundred skeletons were exhumed from the cemeteries at the Chaves Pass ruins, many of which were brought back for examination. These were of the brachycephalic type, the majority with well-marked artificial flattened occipital regions. From a superficial examination they appear to resemble those of the Salado-Gila ruins, but their affinities will be discussed in a special memoir.

Two of the skulls found in the excavations at Chaves Pass had frontal and facial bones stained green. I suppose this was due to the fact that copper carbonate was placed on the face in funereal rites, and that after decay of the tissues, the color stained the bones of the face.

The only specimen of metal found in our digging was a copper bell from the cemetery at Chaves Pass. This bell was found ten feet below the surface of the ground with a human skeleton. It is identical with bells found in graves in Salado Valley, at Casa Grande and old Mexican ruins, and has the same form as the clay imitation described by me from Awatobi, in my report last year. I see no good ground for the suspicion that this bell indicates Spanish influence, for its form is identical with those made and used by Mexican and Central Indians, of gold and copper prior to the advent of the Conquistadores.

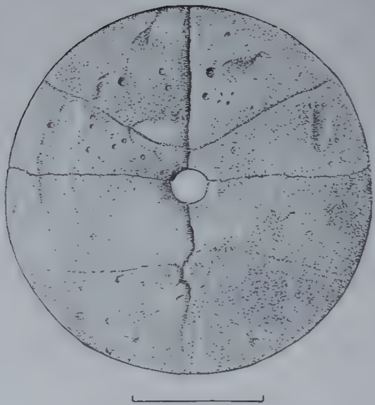
The flat stones with perforations, which, as already shown, were marked indications of the graves at Homolobi and the Chevlon ruin, were not found at Chaves Pass, for this kind of stone does not occur



ROUGH WARE, DECORATED.
(Chevlon, No. 157095.)

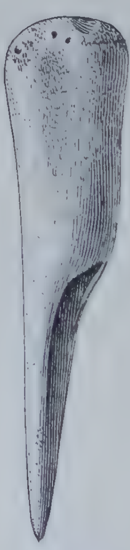
MYTHIC BIRD.
(Food bowl, Chaves Pass, No. 157563.)

STICK USED BY STICK SWALLOWER.
(Chevlon, No. 158076.)



DISK OF TURTLE SHELL.
(Chevlon, No. 157841.)

BONE IMPLEMENT.
(Chaves Pass, No. 157867.)



BONE AWL.
(Chaves Pass, No. 158097.)

CARVED BONE AWL.
(Homolobi, No 157866.)

there. The surroundings of Chaves Pass afforded other materials to cover the graves. This region furnished logs, which were generally used in covering the graves. In digging into the cemetery, we invariably found, at varying depths, a number of these logs laid side by side, resting on stones at each end. These logs were always found to cover a body, sometimes, two or more, laid at full length. Oftentimes these log coverings were but a few feet below the surface, and again 8 or 10 feet. When the dead were buried the food vessels were placed beside the body and head, the logs laid above the corpse, and additional stones placed at both ends of the covering. The weight of soil above these logs, accumulating for a long time, combined with decay of the wood in many instances, had pressed down on the bowls so heavily that many were broken. The accidents of this kind to the mortuary pottery of the Chaves Pass ruins far outnumbered those at Homolobi or the Chevlon ruin.

The pigment used by the people of Chaves Pass in painting their mortuary prayer sticks was not a green copper carbonate, but the blue azurite, a considerable quantity of which was found in small paint pots in the graves. The other pigments which were found were yellow ocher and sesquioxide of iron. Implements in the Chaves Pass ruins, made of bone, were particularly fine, the best of which were made from the leg and other bones of the antelope. The bones of the wild turkey afforded suitable material for bodkins, awls, needles, and the like. There were several bones of a bird made into implements with a hole punctured midway in their length, resembling the whistles, *tatükpi*, still used by the Moki priests in their secret religious rites. There were likewise short sections of bone about a half inch long, flat on one side and round on the other, upon which the marking of a string was plainly seen. Apparently these were once tied together in pairs, but although I found many at Awatobi and a few at Sikyatki, and others at the ruins on the Little Colorado, I am as yet ignorant of their probable use. The skull of a dog was found in one of the graves.

There was taken from the ruins of the Colorado Chiquito, near Winslow, and from Chaves Pass, a type of ancient pottery, which has never been found in the ruins scattered over the Moki Reservation. It is unrepresented in the large collections from Awatobi and Sikyatki.

This kind of pottery is decorated with black, brown, or red lines *with white margins*, and is very common in the cemeteries of the ruins along the Little Colorado. This limitation, which subsequent researches may modify, indicates a well-marked difference between old Hopi pottery and that of the ancient Patki peoples.

The pottery from the Chaves Pass ruins, as would naturally be expected, differs from that of the ancient ruins near Walpi even more than that of Homolobi and the Chevlon ruin. The peculiar cream-yellow ware, a division which includes more than 90 per cent of the ancient Sikyatki and Old Cuñopavi ceramics, is hardly represented at Chaves

Pass, while the red, the black, white and red, and the white and black divisions make up the great majority of mortuary vessels from this locality. As a rule these vessels, as is natural, are similar to the ware from Homolobi.

The striking figure of a bird on the interior of a food basin of red ware is no doubt one of the innumerable mythic birds which figure so conspicuously in modern Hopi ceremonies.[1] The long projecting beak is a characteristic of many masks used in modern presentations in Katcina dances.

The only quadruped which was found depicted in Chaves Pass pictography was a representation of the raccoon, Lakana.

This animal, like many others, has its mythic prototype in the Hopi pantheon, although, as far as known, this is the first proof from objective evidence that it was conspicuous in ancient pueblo mythology.

The various kinds of pottery found in the Chaves Pass ruins, and the geometrical designs upon them, are practically identical with those of the ruins of the Colorado Chiquito (Homolobi, Chevlon), and the same as the fragments which I have seen from the ruins of the Verde Valley. If similarities of this nature mean anything they mean that the people of the Verde Valley and the lower Colorado Chiquito were formerly closely related. Trustworthy traditionists of the Patki family at Walpi told me, long before I knew of this resemblance, that their old men said *their ancestors built the pueblos of the Verde Valley.*[2]

DESCRIPTION OF THE ANCIENT PATKI PEOPLE.

I am led by my studies of these ruins to the following conclusions in regard to the ancient Patki people:

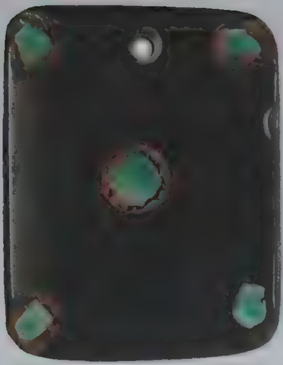
They were of short stature, with brachycephalic heads, more or less distorted by pressure in infancy. They lived in pueblos constructed of clay or stone, raised crops of corn, melons, squashes, cultivated cotton, and made garments of agave, yucca, cotton, and cedar fibers.

They rarely buried their dead in the floors or walls of their houses, but generally just outside the walls of their pueblo, only a few feet away.

For ornaments they wore shell, bone, and turquoise variously worked. The most elaborate forms of these ornaments were shell and turquoise incrustations on wood, shell, lignite, or bone. They may have worn bone and shell ornaments in their hair, but the women before marriage dressed their hair in two whorls, one above each ear, had ear pendants made of rectangular fragments of lignite set with turquoise, bone incrusted with the same, or simple turquoise. Both sexes had armlets,

[1] See the ceremony of the Siocalako and the Zuni Shalako. The former I have described in the Fifteenth Annual Report of the Bureau of American Ethnology.

[2] I am told by Dr. Mearns that a Hopi visitor to Camp Verde, long before I went to Tusayan, told him that "Old men Moki" built the pueblos of the Rio Verde.



a

b

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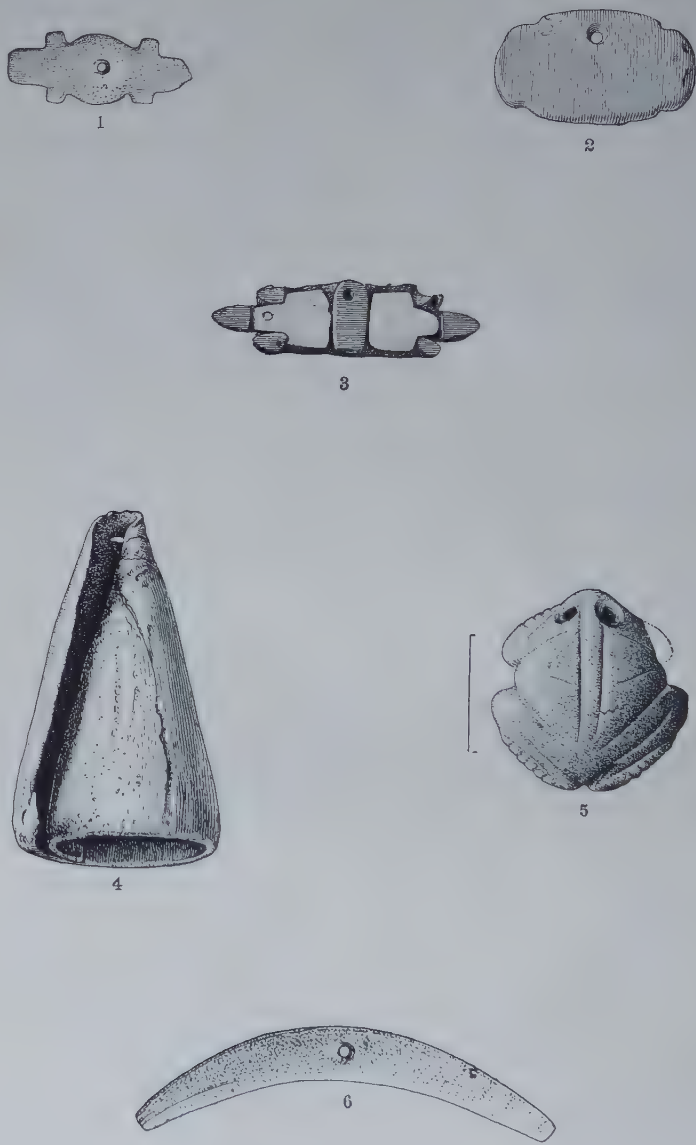
A Hoen & Co., Lith

INCRUSTED ORNAMENTS AND LIGNITE GORGET.



1. SHELL ORNAMENT.
(No. 158074.)

2. STONE PENDANT.
(Homolobi, No. 156903.)

3. MOSAIC PENDANT.
(Chaves Pass, No. 157840.)

4. SHELL USED FOR RATTLE.
(Chevlon, No. 157847.)

5. SHELL FROG.
(Chevlon, No. 157310.)

6. SHELL ORNAMENT.
(Chevlon, No. 157251.)

wristlets, and finger rings made of the marine shell, *Pectunculus giganteus*, sometimes inlaid with stone. They made basketry like that still manufactured at the Moki pueblos, Oraibi, and the Middle Mesa, and wrapped their dead in coarse matting of rushes or other fibers.

The priests made elaborate pahos or prayer sticks, some of which were several feet long, and painted them with yellow, green, blue, red, white, and black pigments, the same as those used by their descendants. They prized for ceremonial purposes quartz crystals, stone concretions, and fragments of obsidian. They were acquainted with bells made of copper. They had rattles of sea shells and wore fringes of shells on the margins of their garments. In ceremonials they made use of stone slabs painted with figures of animals which frequent water.

The warriors were armed with bows and arrows tipped with stone and obsidian points. They had mauls and clubs, stone hammers, celts, and axes. They made needles, bodkins, and awls of bird bones, antelope tibiæ and ribs, which they sometimes carved in imitation of animals.

The women were adepts in the manufacture of earthenware vessels, which they decorated with elaborate figures in several colors. They were familiar with the art of glazing pottery, and practiced etching of the same to a very limited extent.

They buried their dead just beyond the outer home walls, and deposited with them various votive offerings, pottery, basketry, ceremonial and other paraphernalia, having first painted the face and wrapped the body in matting. Over the grave, as environment dictated, they placed square or rectangular perforated stone slabs, or covered the corpse with cedar logs resting on stones at either end and weighted with the same at the extremities.

In their mythology, the symbols on their pottery indicate that they recognized the sun and spider as powerful deities. They worshipped the rain clouds, lightning, snake, tadpole, frog, and various mythic birds. The designs on their pottery was similar to that of the ancient Tusayan people; broken encircling bands, terraces, spirals, and zigzags were common. The leaf or flower was not used in artistic decorations, and human figures only sparingly copied. They entertained an idea of a future life, and associated the dead with rain gods. With the deceased they deposited votive offerings in food vessels, and buried costly (to them) property with the defunct.

CUÑOPAVI.

The discoverers of Tusayan in 1540 sought "seven cities," but there is no evidence that they found more than five, for the narratives of visitors in the sixteenth century discredits the vague report of seven Tusayan pueblos. At the time Tobar visited this province, and for a century later, there were probably only five pueblos on what is now called the "Moki Reservation." These villages were Awatobi, Walpi,

Micoñinovi, Cuñopavi, and Oraibi, names which can all be recognized in Espejo's list of 1583.

Of these pueblos the first mentioned has been destroyed,[1] and the last still occupies its ancient site, while the others have been moved to the tops of adjacent mesas.

Old Cuñopavi, or "Cumupabi," as it was known in earliest records, was situated in the foothills near the spring east of the mesa on which stands the present pueblo. The remnants of the ancient house walls indicate that it was a village of considerable size, and of an old architectural type. It had a mission in the early days, the walls of which are now used as a sheep corral. The cemeteries of old Cuñopavi were very extensive, some situated near the old walls and others more distant. A tract of sand, about a half mile east of the town, was a burial place, which is thought to have been used by the old Cuñopavi people.

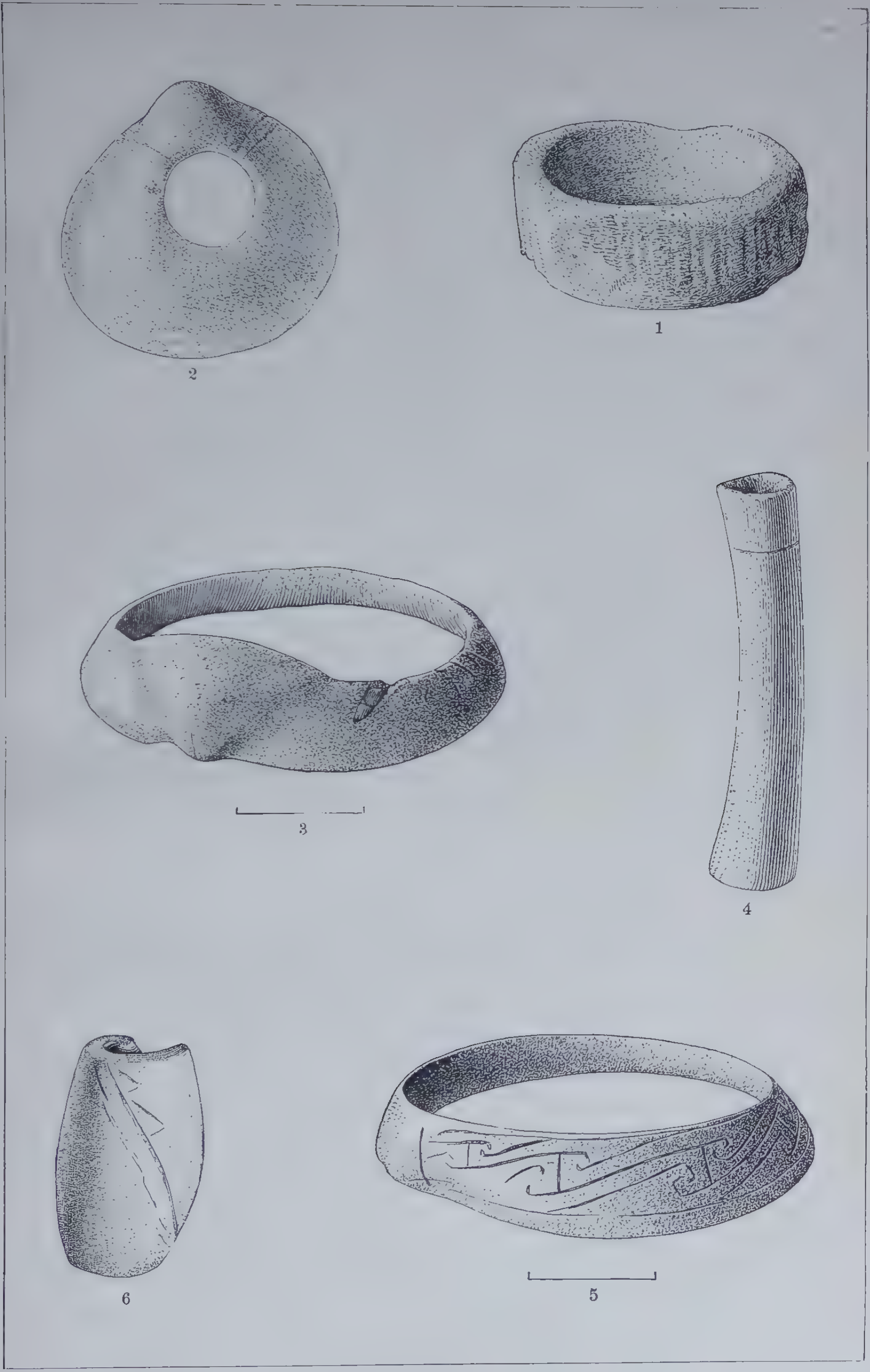
We camped on the edge of this cemetery, as near as we could get our wagon to the spring, and I began work with high hopes of success. I was aided by a large force of native workmen from Walpi, but was obliged to suspend my explorations after two very remunerative days' work, during which over one hundred and twenty beautiful pieces of pottery had been exhumed. The chief of Cuñopavi, incited by the chiefs of Micoñinovi and Cipaulovi, he said, objected to my digging in the ancient cemeteries on the ground that such work would create great winds which would blow away rain clouds and thus deprive them of rain for their farms. He likewise stated that disturbing the graves would incense Masauñh, the god of death, and kill the little children. After a long talk with the Cuñopavi chief, Naciliptewa, whose feelings I respected, I came to the conclusion that the time was not yet ripe for archæological work so near the inhabited pueblos. The necropolis of Old Cuñopavi is one of the richest in scientific treasures in Tusayan, and will some day yield to the student a wealth of material destined to throw a flood of light on Tusayan cults and customs in prehistoric and early historic times.[2]

The pottery from Old Cuñopavi is most closely allied in texture, color, and symbolism to that of Sikyatki, the best in the Southwest. This ware is, as a rule, cream or yellow colored, very smooth, made of finest paste, but never glazed. No specimen of the red ware which forms

[1] Smithsonian Report, 1895: Coronado sought "seven" cities of Cibola or Zuñi, and Castañeda, Motolinia, and others said that Cibola had that number. Jaramillo, however, speaks of but five pueblos in Cibola. Camuscudo mentions six, and a few years later Espejo gives names of the same. In Oñate's act of obedience in 1598 only six pueblos are mentioned. To reconcile Castañeda's and Oñate's enumeration, Bandelier considered it "as probable that one village was abandoned within forty years after Coronado's departure;" but Jaramillo, who gathered his data "on the spot," and was with Castañeda on Coronado's expedition wrote, "Hay en esta provincia de Cibola, cinco pueblezuelos, etc." Modern research has not yet demonstrated that Coronado found "seven" pueblos in Cibola or Zuñi.

[2] A beautiful collection was taken from this locality in the spring of 1897, and sold to the Field Columbian Museum.

PLATE XLVI



1. KAOLIN DISK.
(Chaves Pass, No. 157928.)

2. SHELL ORNAMENT.
(Homolobi, No. 156391.)

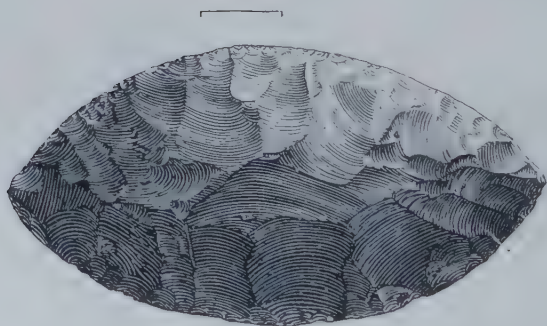
3. ARMLET WITH INLAID TURQUOISE.
(Chevlon, No. 157295.)

4. BONE TUBE.
(Homolobi, No. 156898.)

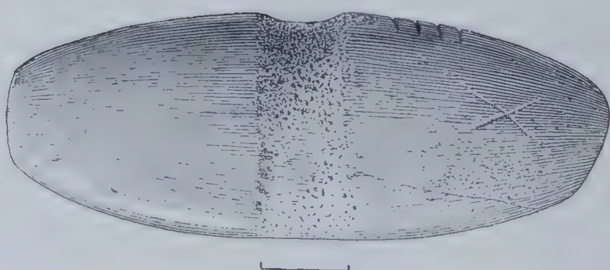
5. INCISED ARMLET.
(Chevlon, No. 157843.)

6. SHELL ORNAMENT.
(Chevlon, No. 157845.)

BIRD DESIGN.
(Cuñopavi, No. 157795.)



STONE IMPLEMENT.
(Homolobi, No. 157895.)



STONE IMPLEMENT.
(Chevlon, No. 157024.

such a conspicuous feature in the Colorado Chiquito pottery was found, and there were only two specimens of black and white.[1]

A much larger number, proportionally, of bowls decorated with figures of mythic personages were found at Cuñopavi than in the Winslow ruins, the proportions being about the same as at Sikyatki. From what we know of ancient Tusayan ware and its decoration, I believe that its specialization in decoration shows an advancement over all other quarters of the pueblo area, and that the potters' craft in that province in prehistoric times was more highly developed than elsewhere in the Southwest. The varieties of pottery found in Cuñopavi include the coarse-coiled patterns, cream-colored and black and white. The cream ware was very smooth, but without glaze, which, however, forms a well-marked feature of certain specimens from the three Homolobi ruins.

No form of pottery was found which was essentially different from those taken at Sikyatki, and the mode of burial appears to have been identical in the two pueblos. Considering the decorations as so much pictorial material, I find little variation in geometrical patterns used in Sikyatki and Cuñopavi or the Homolobi group of ruins. The drawings of animals differ somewhat from those of the latter region, and my collection in a way supplements the known ancient Tusayan paleography. As with the decoration of other prehistoric Tusayan ware, figures of mythic birds predominate over those of other animals, and the feather is a constant feature in ornamentation. I have introduced copies of some of the more striking or novel forms of animals represented in the ancient Cuñopavi ceramics.

One of the most striking designs on the food vessels evidently represents a bird with elongated beak, a tuft of feathers on the head, and an elevated wing. On the throat there is a figure of a terraced rain cloud, and the three feathers of the tail are represented in false perspective. The significance of the ring is unknown to me in this connection, although the circle is at present a symbol of the horizon. A more conventionalized figure of a bird from another food basin has wings and tail, but a remarkable head, which represents a mask. The face is represented by a rain-cloud figure with parallel lines over the mouth resembling falling rain. Above it there is the conventionalized symbol of the dragon-fly. The appendages to the sides of the mask recall those still used at Zuñi and Walpi in the personifications of Katcinas. The horn on one side and the rectangular appendage on the other suggest the personage

[1] The fine yellow ware, which we may call Tusayan ware, is limited to the ruins of modern Tusayan. In the area where it is found the ceramic art reached a very high degree of perfection, and the symbolic decorations show a higher development than anywhere else among the ancient people of the Southwest. The pottery of the Colorado Chiquito ruins, in which I include those of the ancient villages of the banks of the Zuñi River, is red in color, coarser in texture, and, as a rule, simpler in symbolic decorations. This ware may be known as the Little Colorado ware, which has many advantages over the nomenclature "ancient Zuñi ware."

called Caiastaca. Figures which can be referred to Katcina masks are rare in the most ancient Tusayan paleography, which has led me to a belief that this cult is a late introduction among the Hopi.[1]

The two figures on an adjacent plate represent a true Sikyatki style of ornamentation, variations of which can be traced with great clearness, but which, as far as I know, have never been found outside the present boundaries of Tusayan. These figures represent a symbolic bird, highly conventionalized, but with tail feathers, wings, and part of the body easily distinguished.[2]

A single specimen with the decoration of a reptilian figure was found, and this was pronounced by Kopeli, the Snake chief, to represent the Plumed Serpent. The design had little likeness to the symbolism at present adopted to distinguish this mythic monster.

Unique in the collection from Cuñopavi, and very rare in ancient pueblo pottery, are two food bowls furnished with spouts. One of these has depicted upon it a mythic bird very much conventionalized, and the four reeds of a game of chance still in vogue among the Zuñis.[3] The reeds used in this game I have already referred to as found at Chevlon.

The figure of a bird with a long upper beak recalls the parrot, a bird so often used in decoration of pottery farther south, and whose feathers are so highly prized for ceremonial purposes. The two feathers which project from one side bear the conventional marks of the breast feather of the eagle.

The two bowls in the following plate are highly conventionalized, but the figures evidently represent the tail and two wings. The star is associated with the great harpy, Kwataka, whom I have shown to be one of the prominent mythological characters of ancient Sikyatki.[4]

The Cuñopavi pottery is most closely related in symbolism to that of Sikyatki, and is very similar to that found at Old Walpi.[5] Its likeness to the pottery of Awatobi is more distant, and the same is true of Sikyatki, for the ancient pottery of Awatobi is closer than to either the ruins of Homolobi, Chevlon, or Chaves Pass. This resemblance is suggestive, and may later be shown to mean a closer resemblance of the people of Awatobi to those of the south than is now suspected.

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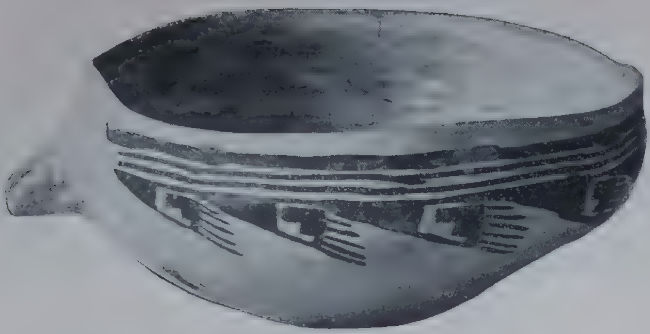
[1] The Katcina cult in Tusayan is intimately associated with the Honani or Badger people.

[2] From the closeness in symbolism and the resemblances in the character of the ware there seems every reason to believe that Old Cuñopavi was inhabited synchronously with Sikyatki. The historical argument does not prevent an acceptance of this conclusion.

[3] See Owens's account of Zuñi games, Popular Science Monthly, 1894. The symbolic bird depicted on the food basin with the four reeds is a patron of gamblers.

[4] The modern Hopi have many legends connected with this harpy, or bird monster.

[5] Old Walpi consisted of two pueblos situated on the terrace below the east mesa, and were formerly inhabited by the ancient Walpians. The latter lies to the north, the former to the west of the present pueblo, where extensive ground floors are still visible.



BOWL WITH SNOUT.
(Cuñopavi, No. 157817.)

GAMBLING REEDS, AND BIRD.
(Cuñopavi, No. 157735.)

MYTHIC BIRD AND GAME OF CHANCE.
(Food bowl, Cuñopavi, No. 157714.)

MYTHIC BIRD.
(Food bowl, Cuñopavi, No. 157134.)

Our excavations at old Cuñopavi, interrupted in their inception, were too small to betray much of ancient customs, but we found in the graves such a close resemblance to those of Sikyatki that there must have been a strong likeness between the two peoples. The decorations on pottery are closer to those of Sikyatki than to that of Walpi or the Middle Mesa. Cuñopavi is no longer a pottery-making pueblo to the same extent as Oraibi and the East Mesa, but in old times this condition does not seem to hold.

CONCLUSION.

In order to show the advance made in the interpretation of the problem of the origin of the Hopi Indians by the fieldwork of 1896, it may be well to close my report with a summary of theoretical results obtained by the expedition. The objective material collected demonstrates that ancestors of some Hopi clans lived in ancient times on the Colorado Chiquito and at Chaves Pass, over a hundred miles south of Walpi, a few miles from the head waters of the Gila Salado drainage area. The material from the most southern ruin examined is almost identical with that from the Verde Valley. The step which remains to be taken is a searching investigation of the ruins from the crest of the Mogollones south to the great ruins near Tempe and Phœnix. When that is done we will have what has never been done before in southwestern archæology, the tracing of a migration legend of a pueblo people, step by step, by archæological methods.[1]

The material collected from the Chevlon ruin shows that some Zuñi clans probably formerly lived farther down the river than their descendants do at present, and that their culture was almost identical with the Hopi, who lived in the neighborhood or possibly in the same pueblo. The arguments bearing on this conclusion can be satisfactorily stated only by a technical discussion of the material.

Studies of the habitations of the ancient people of the southwest have shown me, as stated in my report for 1895, that the culture of the people who built cliff houses, cavate dwellings, and villages in the plains or on mesa tops, was the same, and that these different architectural structures are adaptations to environment. I am convinced, from my studies in 1896, that the color and character of ancient pottery follows a similar law, and varies according to the material employed. In other words, that a classification of pottery by colors is purely arbitrary and useless in separating different pueblo people. The character of the symbolism is more important.

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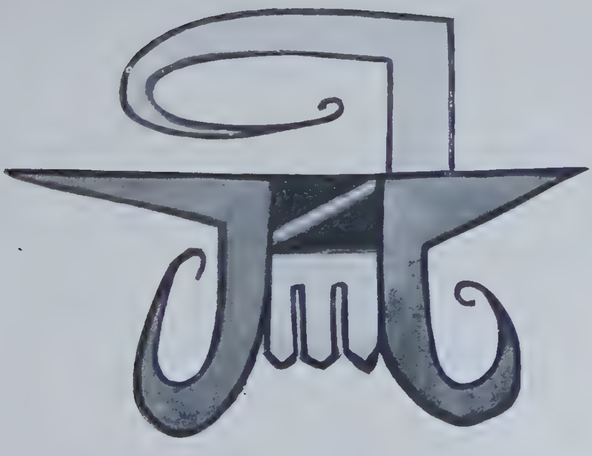
[1] It may be suggestive to show that the ruins at Chaves Pass are twice the distance from Walpi that they are from Casa Montezuma in the Verde Valley, and almost midway between the present Tusayan pueblos and those near Tempe, near the Salado River, in southern Arizona. The ruin at Rattlesnake Tanks, which I have not studied, lies midway between the Verde ruins and those at Chaves Pass, on the trail connecting them.

PLUMED SNAKE.
(Food bowl, Cuñopavi, No. 157769.)



SYMBOLIC BIRD.
(Food bowl, Cuñopavi, No. 157771.)

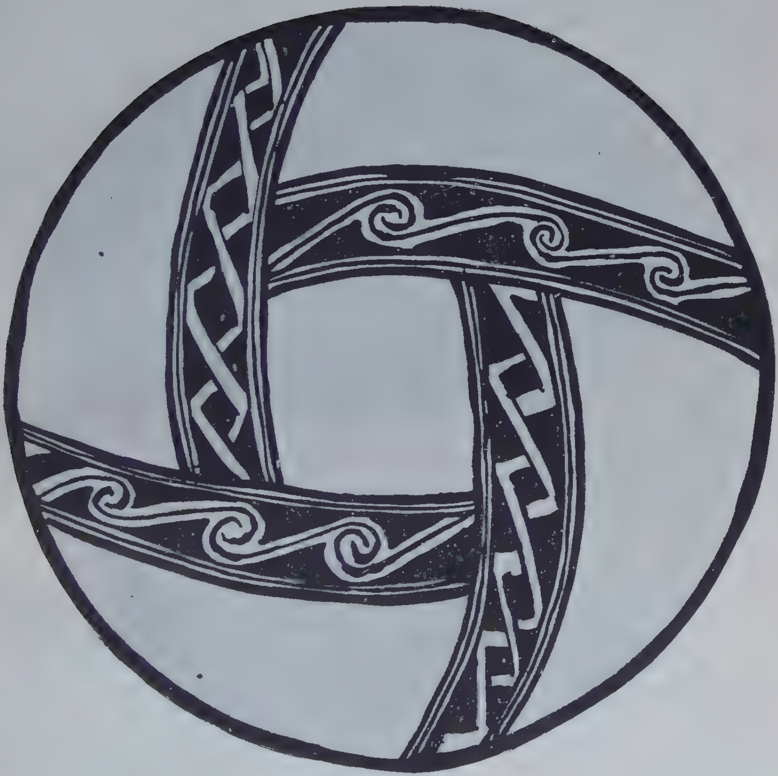
BIRD-SHAPED VESSEL.
(Chevlon, No. 157909.)

MYTHIC BIRD.
(Food bowl, Chevlon, No. 157264.)

DUCK-SHAPED VESSEL.
(Chevlon, No. 157018.)

BIRD FIGURE.
(Food bowl, Chevlon, No. 157084.)

THREE LINES OF LIFE.
(Food bowl, Chevlon, No. 156138.)



GEOMETRICAL DESIGNS.
(Food bowl, Chaves Pass, No. 157539.)

A

B

A Hoen & Co., Lith

RED WARE DECORATED IN BLACK AND WHITE.

WAS PRIMITIVE MAN A MODERN SAVAGE?

By Talcott Williams.

The early primitive, primeval past has three witnesses—its early tra-
lition, conscious and unconscious; archæological research into its emains, and the anthropological study of existing savage and barba-
ian races. These three sources sum our knowledge of the beginnings f things. It is the current tendency to challenge the value of tradi-
ion, to exalt the value of inferences drawn from anthropology, and to nterpret all archæological discovery in the light of our knowledge of he savage of to-day. His study has played the same part in deter-
nining our view of the dawn of history as has the study of the lower rganisms in determining our conception of the origin and development f the human species. Both have been accepted as repeating in their resent activity the unknown past. From both have been drawn the nferences on which rest current theories as to the beginnings of his-
ory and the descent of man.

The value of both methods of study is not altered because it is neces-
ary from time to time, with new knowledge, to readjust our past pplication of recorded facts to an unrecorded past. This perpetual eadjustment between our knowledge of facts and our application of hem is the measure of the progress of science. In all fields it inex-
rably proceeds; in all it marks not reaction but growth. If, in biol-
gy, the recapitulation theory is less implicitly accepted than it once vas, as spelling all the riddle of fetal changes, it is not because less is nown of embryology, but more. If new controversies as to the plas-
icity of the early cell and as to the capacity of all cells either to acquire r transmit hereditary or acquired influences postpone the solution of ome of the issues of life whose discovery seemed near twenty-five ears ago, it is not because the true solution is more distant than it nce was, but because it is nearer. The readjustment which has been ecessary in biology in employing the lowest organisms to explain the rigin of human life is equally necessary and equally probable in the ttempts to explain the origin of human society by the use of the low-
st forms of organized society. These attempts have left on us all the npression and image of the progress of man as beginning with a sav-
ge—bestial, degraded, and repulsive, lower than the lowest now

known—passing upward through incessant centuries of savage warfare in which each worse stage has been succeeded by a better, all finding their reflex and counterpart in the grim and bloody record of the anthropologist, which has in it many savage infernos but no primeval Eden.

This conception of the beginnings of human society rests to-day on the uniformitarian view that the savage of the youth does not materially differ from the savage of the maturity of the race. The earliest savage of the past is assumed to be like the lowest savage of to-day, and the well-nigh universal assumption is that the origin and only origins of human institutions must be sought in tribes engaged in a perpetual warfare with those about, cannibal in their habits, in their religious conceptions the prey of the terror-stricken animism of the savage, as we know him, in their sexual relations given to exogamous marriages by capture or to endogamous marriages sprung from communal maternity, both bestial, below the larger mammals and birds, among whom a fairly loyal monogamy not unusually exists. The fountain of government is to be found, and found alone, in a matriarchate which implies fugitive paternal relations or a patriarchate which was always the precursor of and was usually accompanied by polygamy. Out of this dark background of war, rapine, robbery, rape, fornication, and incest, by pathways as dark of idolatry, polytheism, polygamy, and slavery, we are asked to believe that man slowly developed into monotheism, monogamy, the family, freedom, equality, and law. The contrast between the origin and end of this human pilgrim's progress must have often struck the candid observer. The difficulty may lie in the facts. It may lie in the theory. If in the latter, it will not be the first time that the real obstacle to acceptance has been, not in the facts, which, accurately stated, always explain themselves, but in the theory which is presented in the name of science, but is, as all mere theory must be, the badge of ignorance and the open proof that the facts are not yet fully known.

Of the existence of cannibalism, for instance, as a fact on the part of prehistoric man, in some quarters and places, there can be no reasonable doubt. Whether this single habit was in the first place universal, in the second place primitive, and in the third place connoted, all that in the modern savage accompanies cannibalism is a matter of inference in the present state of our knowledge. There is no question that certain representatives of prehistoric man, living miserable lives in caves, at or near the close of the glacial epoch, in a region where the struggle of life was severe, were cannibals. This is also true of very early man in more favorable conditions in Southern Egypt and of early remains in Japan, a region where, as in North Europe, subsistence must have been difficult under primitive conditions. Whether in friendlier parts of the temperate zone, farther on one side from the Arctic Circle and on the other from the Tropic of Cancer, cannibalism

was universal, we do not yet know. A large explanatory field in myth, legend, and religion rests, however, on the assumption, first, that cannibalism was universal, and second, that it was primitive, though the habit is, as we know, in some modern savages of recent introduction and adoption. Yet, before admitting that cannibalism and its other concomitants were both primitive and universal, is it not fair to ask—since the higher apes are in many instances decently monogamous and comparatively peaceful—for more proof before we are fully persuaded in our own minds that the particular pithecoid ape which aspired from the brute to man, sank, on developing human traits, into the savage mire in which most prehistoric theory plunges him?

This theory rests on the inference—and let us remember it is only an inference—that the modern savage explains primitive man, and this inference rests in its turn on the assumption not only that the modern savage and primitive man are alike in culture, but that they are also alike in character and that they both act, one in the past and the other now, under similar conditions. They may. In one most important particular there is no proof that the essential condition is similar; quite the contrary. The modern savage is under pressure. In Australia, at his lowest, he is under the pressure of a desiccated and desiccating continent.

Indisputably a decreasing precipitation has made the struggle for food more severe for him within a comparatively recent period. The Polynesian savage is under the pressure of exiguous insular territory. The Malaysian savage is under hostile intertribal pressure, stimulated by the ease of water communication in an island and tropical world. The African savage is under a like pressure, relieved by obstacles of transit on a continent where, taken collectively, the coast line is in small ratio to area, waterways few, and deserts many. The Eskimo is under arctic pressure. Nearly everywhere the modern savage is or has been under contiguous civilized pressure.

It is a familiar truism of both the savage and the barbarian that each owes his worst qualities to this pressure. Deterioration succeeds wherever it is applied. Under pressure civilized man may be at his best, as witness the high civilization which the needs of a cold winter will develop in those who face it with some civilized capital; or the rapid development of our railroad system under the pressure of transcontinental distances. Under pressure, be it heat, cold, a spare food supply, difficult communication, or civilized neighbors, a savage or a barbarian is at his worst. For his development some opportunity for expansion, some freedom from pressure, seems essential. Nowhere is it clearer that the pressure of civilization works ruin for him than on this continent. Here, too, if this was escaped until a late period, there existed in two or three great centers, if not the pressure of civilized barbarism, at least the pressure of a barbarian civilization in Mexico, Central America, Peru, and perhaps elsewhere.

Everywhere, then, the savage and barbarian, who is held up as the mirror and reflex of our past, is under pressure. Where the climate is unfriendly this pressure is due to nature; where the climate is friendly, to man. Primitive man may also have been under this alternative pressure. It is possible that, before the first halting steps were taken which carried man from savage to barbarous life and set his feet in the path that led to civilization, the earth, or, to be more accurate, the Euro-Asian continent along the belt where physical conditions were favorable, was already full of men. But is it not more probable that it was empty? The relics of paleolithic man point to wandering and to scattered centers of activity and population rather than to a universally diffused population. Much must be collected, collated, and studied before this question can be unhesitatingly answered one way or the other. A slender population existing through long eras will leave as thick a deposit of stone implements, for instance, as would a large population in a short time. The former seems a more probable proposition and a more reasonable deduction than the latter. The balance of proof and probability are for an empty earth in the regions where civilization began at some date which, for our present purpose, it is unnecessary to fix precisely, but which few would be inclined to place earlier than 10,000 B. C., and most at about 6,000 B. C., or within a millenium of this period. The early savage, as he began in some favorable site the germinant origins of civilization, would, therefore, be without pressure, and to pressure much in the modern savage must be attributed. Around each of these early centers for civilization would stretch an elastic zone of unoccupied and for many generations undesired territory. Into this elastic zone each tribe which began to ascend into civilization in some river valley, island, coast, or range would grow without pressure and without antagonism. The trader would cross this zone before the war party penetrated its friendly protection. For three early and favorable nests of primitive culture—whether the first or which was the first I do not assume or assert—in the Euphrates Valley, in the Nile Valley, and in southern Arabia, special physical conditions emphasize the protection which this elastic zone offered. Peace, not war, would be the normal condition of these antecedent communities in which the flower of savage life was setting into barbarism and slowly fruiting into civilization. Each, surrounded by an empty space, would develop, untouched, for many centuries, and its culture would be fostered by peace and not forced by war. Marriage by capture would be rare or unknown. The family would early develop. Woman would come to occupy a far higher position than in tribes under the pressure of modern savage life, where she is the booty of the strong and the drudge of the successful warrior. In the happy and fortunate but not improbable isolation due to a sparsely settled earth about and a well-settled territory within, the separate ownership of land would early develop and bring with it the arts, the leisure, and the culture of

the landowner. The priest in a community so situated would occupy a higher position than the warrior. Removed from strife and protected from attack, the early type of religion would develop a beneficent view of the Deity. Monism in some monotheistic shape would become the dominant and interpretative but not the exclusive form of national faith, because an homogeneous concentric national growth would long maintain the supremacy of the central shrine. Government would be benign. Conquest would not be its chief object, because about and without would be no tempting object of attack. The arts would flourish and it might easily be that some Sheikh el Beled, such as now stands in wood at Cairo, or some scribe and architect, such as sat at Tellah and now sits in the Louvre, would surprise us by an achievement in sculpture which later generations were not destined to equal. This is not only possible, as an hypothesis, if an empty earth spread an elastic zone about each favored and favorite nidus of civilization, but I unhesitatingly appeal to every student of the early stages of Babylonian, Egyptian, Arabian, and Chinese civilization if the development which I have sketched does not more nearly meet the known and recorded facts of the dawn of the history of each than does the assumption that a savage possessing the culture of the Papuan or the negro was slowly prepared by perpetual tribal war, by brutal sexual relations, and by terror-stricken superstition for the upward ascent of man.

In due time, it is true, the elastic zone would be taken up by the increase of population, external and internal. War and conquest would come. The structure of the state would be remodeled. The warrior king would move to the head of the state and exercise the despotic direction of its affairs. Earlier liberties would disappear. Arts and industries would deteriorate. The national religion would divide into polytheistic conceptions. It would gain in ferocity and organization and lose in elevation and ethical character exactly as would the community itself. With conflict and conquest slavery and polygamy would play a larger share in the national life. The dangers and debauch of war would stimulate superstition. The militant would succeed the industrial type of society. In short, there would come the precise deterioration in the national activities, conscience, and consciousness which is perceptible in both Babylonia and Egypt as outer contrast begins. In the present state of our knowledge, in which the dim perspective of centuries too often crowds together in our discussion dates widely disparate, it is not possible definitely to determine the precise time of this change, but that some such downward movement occurs in both countries somewhere between and about three thousand five hundred to two thousand five hundred years before Christ, no one will, I think, be inclined to deny. As the earth fills also about these early centers, there begins to fall on their records the pressure of possible or actual conquest from without. New cruelties appear, a lower moral temper and blunted morality, with a host of those superstitious

indicia which have been deemed the signs and survival of a savage origin, but which in the secondary stage of these communities and in the modern savage are the product of pressure, and not the normal fruits of the primitive development of man.

Much, inscrutable and inexplicable on the theory that all in ancient and much in modern cultures is to be explained and read in the light and lesson of the debased savage, becomes rational and luminous on the theory just sketched, which allows for the absence in primitive culture of the precise pressure under which the modern savage lives and has lived for generations, and through which he has become what he is. The golden age of peace, virtue, and justice, which appears in every popular mythology, and which it is at once crude and unscientific to dismiss as a myth, squares itself with the development just described. The diffusion of primitive myths, primitive culture, and primitive commerce becomes easily explainable when we remember how freely among such isolated communities the trader would pass.

We know that he thus passed among American Indian tribes. The native copper-gold alloy of Bogota has been found in pre-Columbian ornaments in south Jersey. Native copper of Michigan was carried all over the continent, and the conch shells of its sea coast penetrated to its center. The turquoise of our southwest is found in ancient graves a thousand miles away. In the old world, the diffusion of jade in prehistoric times is a familiar and typical example of like phenomena. Tin found at opposite extremities of Europe and of Asia spread over all the space between, the terms of the two extremities meeting near the Iranic plateau. Copper from the Biscayan mines, the mines of the Atlas, and the carbonate of copper of the Taurus, spread over all western Asia and Europe. Such commerce would be impossible if the savage were in perpetual tribal war, but, as a matter of fact, with our own American Indians, the instant the zone of pressure caused by infringing civilization is passed, there is found the utmost freedom for the trader who moved with relative and remarkable security between tribes at war and with complete safety between tribes at peace. Nor can any one who has been fortunate enough to break the bounds of civilization and leave behind him its frontier of hate fail to be struck with a new attitude toward the stronger and a hospitality which literature, wiser than anthropology, has justly termed a primitive virtue.

So with the diffusion of myth and custom. To our thoughts, full of the wars of history, and our imagination, affected by the specter of strife as the normal condition of the savage, isolation seems the characteristic of primitive culture. Communication was, however, probably freer than at a later period, when conflicting frontiers had turned hospes into hostis. Once diffused, however, the new frontiers which divided what had once been an elastic and easily penetrated zone prevented further intercommunication, and this may, perhaps, explain so much which is insular in the "fauna" of religions, but an insularity which at so many points hints an early continental communication.

The savage theory of primitive culture is forced also in such records as exist of early times to lay great stress on incidents and accidents, the petrifactions of the narrative, and to attribute the main majestic current of historical record to the myth-making faculty. This is convenient. It is not conclusive. If, however, a different view is adopted, if we think of the empty earth as early bearing separate centers of civilization too far apart to vex each his neighbor, and living at peace with the nameless region between, the conception altogether harmonizes with the broad outlines of such early records as we have, and explains on a simpler hypothesis the "savage" exceptions they contain. The early and later Genesis documents may represent the compilation of records, colored by these successive stages of peace and of war. The entire ethnic theory of the book is of an earth empty and slowly filling until the elastic zone is taken up and inevitable war begins. Movement and immigration are easy on this hypothesis. They become impossible if savagery was spread over the earth and slowly curdled here and there in some happy and defensible coign of vantage into barbarism and civilization. What is true of Genesis is true of all national records and all archæological research. Everywhere is a surprising primitive development. Everywhere this descends into war. Everywhere the war god is the younger god, never the elder, as perpetual war would have made him. If the origins of society stood rooted in perpetual strife, if the endless war of the savage were its early normal condition, and the war chief its first head, mythology would make the god of war the earliest of the pantheon; but, while he is often the favorite national deity, his temple the greatest, his priesthood the most important, and his caste the rulers of the tribe, in the national cult and culture the war god is, as with Ares and with Mars and a dozen more which will suggest themselves, of the second or third generation of deities. I can not, myself, recollect a single instance in which the tutelary divinity of war is figured as a primitive deity, although the rites of hospitality are often committed to an early god, and the protection of the stranger is generally in the hands of such a deity as is natural if general war succeeded general intercommunication over vacant and often peaceful spaces. In general, the succession of deities is from local primitive and comparatively peaceful early gods to gods whose warlike demands require a bloodier sacrifice. Not infrequently, also, though by no means as uniformly as with the war god, the goddess whose worship prescribes, permits, or palliates sexual license, is figured as a goddess later and younger than the goddess who presides over lawful marriage. How frequently, also, in this development of a national and popular pantheon, based on local and tribal cults and shrines, is there elusive esoteric reminiscence of a period when polytheism was preceded by a juster conception of the divine as it is in time generally succeeded by one. Everywhere men look back upon peace and hope for its return. Everywhere nations have their wanderjahre

in their annals when the earth was still empty and happy and young. These numerous coincidences can not be accidental. They unquestionably point to the necessity of revising and limiting the confidence with which the modern savage has been used to explain a nobler past which the surviving savage would have shared, if he had been fit for it, or untoward circumstance had not barred his way. In the end it may be found that even more radical change is necessary in our interpretation of the past, that the only true explanation is that much in existing savage culture represents retrogression, and was never a part of the upward movement of the race. For the present this conclusion would be to err in another extreme. All that can be claimed now is that too much has been made of savage life in explaining the primitive development of the race, and too little of conditions which, once existing, have since disappeared, and, by disappearing, have done much to create the misleading savage of modern anthropology.

BOWS AND ARROWS IN CENTRAL BRAZIL.[1]

By Hermann Meyer.

The present treatise is an introduction to a larger one now in course of preparation. While this larger work is to discuss the distribution of the bow and arrow throughout South America, and to widen the knowledge of her mixed populations by means of a thorough investigation of material in museums and the study of literature, it is the aim of this brochure to point out the system only in general outline, with the comparison of the materials furnished for the classification of bow and arrow, and to set forth for a circumscribed region—the Mato Grosso—how, through the harmonizing of different tribal groups, ethnographic types arise: what share the several associated tribes have had in this creation of groups; and, on the other hand, what ethnographic development within the group each tribe has undergone.

It will not be possible to make an extended review of individual tribes in a preliminary description of the bow and the arrow. This is in view for the later work, and at this time it will be presented only so far as an ethnographic characterization is necessary. In the same way here the review will be only so extended concerning the meaning of these weapons for a tribe as to reveal some variation of the arts by which an advancing or retarding momentum in the ethnographic development has been given.

For investigating the ethnographic materials which furnished the groundwork of my investigation, it was made possible through the recommendation of Professor Bastian, in Berlin, and Professor Ratzel, in Leipzig, to study the collections belonging to the museums in Berlin, Munich, Vienna, Braunschweig, Copenhagen, Stockholm, Christiania, Brussels, Amsterdam, Rotterdam, Leiden, London, Kew, Salisbury, Oxford, Cambridge, Newcastle, Edinburgh, Glasgow, Belfast, Dublin, and Liverpool; and I here express to the directors and conservators of the establishments mentioned, above all to Professor Bastian and Professor Ratzel, and especially to the head of the American section of the ethnographic museum in Berlin, Dr. Seler, my heartfelt thanks for the

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encouragement rendered. Moreover, I am obliged to Professor von den Steinen, to Dr. Ehrenreich, and to Dr. Richard Andree for friendly assistance.

A large number of museums on the Rhine, in Switzerland, France, and Italy, which I had not time to visit, I thank for their promises to render complete my investigations in the future. The rich material of the Leipzig museum was unfortunately at the time, through want of space, packed up and not accessible, yet it is hoped that shortly after the completion of the new museum building it will be possible to make studies there also.

In the study of material stored up in museums one must proceed with the greatest prudence in deciding the matter of locality, for the beginner in this field, who has no knowledge concerning the associations of a specimen, makes false and confused reports. There exist only small collections whose data have any claim to confidence; the great majority of objects are either unknown or insufficiently or falsely labeled. Very many pieces which have been brought together from some estate, or through collectors on the coast, far from their origin, bear absolutely untrue information regarding their provenience. There are many pieces that migrate down a river, even to a trade station near the mouth, and then come into the possession of a traveler who knows only the name of the last place or of the river. Other specimens that the traveler really got from the natives represent not indeed the true ethnographic type of that tribe, since these also could have come into the possession of a tribe through traffic or as booty, as Lucioli narrates of the Ucayale tribes—that slaves among them worked in their own manner. However, by means of a careful comparison of specimens in question with well-identified material it is possible to find out with some certainty their coordination.

In the accessible literature are only a few modern works of any value for furthering this investigation, since the majority of travelers, particularly older ones, have often some other object than the promotion of ethnography, and consequently give only brief notices on ethnographic subjects. Only in the rarest cases do they devote themselves to a detailed description of weapons and tools of a tribe with whom they came in contact. For that reason are to be found abundantly in different accounts of the same tribe contradictory statements, so that even in the utilization of such notices one must use the utmost caution and critical discrimination.

Unfortunately it was not possible for me to identify the substances used in the manufacture of bows and arrows, by which I might have had better data for the fixing of the locality and for proving also the craft marks. A botanist skilled in South American flora, to whom I referred a single little sample of wood for microscopic investigation, declared that among the endless number of South American species of trees he could render assistance only through the leaves or the flowers.

This was unfortunately impossible in the case of the weapons. I must, therefore, confine myself to the repetition of the reports of collectors or quotations from literature.

Since I have expressed these many difficulties which are in the way of a thorough investigation, the reader will perhaps lightly criticise any errors or shortcomings that may appear in my work, especially when I here suggest this is to be merely an effort to throw a little light upon the tangled ethnographic conditions in South America—only a first effort in a larger inquiry, and laying no claim to enduring validity.

The motive in ethnographic investigation is twofold. First, to furnish a contribution to the ethnography of a single group, by which the group as such may be set forth in its individuality. Second, it should be sought to establish upon the foundation of the descriptive part a scheme for fixing the relationship of this group to its neighbors, and, above all, to mankind in general. I say advisedly a scheme, for everyone must be conscious that such investigation can be only one-sided; and as yet one is not entitled to draw larger conclusions and family connections of the people in question. Only when the purely objective ethnographic results compared with linguistic, anthropologic, and ethnologic investigations agree, can the perfect accuracy of the outcome be accepted. Into what dreadful blunders one is led by precipitate conclusions of all sorts drawn from one-sided data is sufficiently known.

That ethnographic and linguistic studies in nowise always lead to the same result may be realized in the examination of every ethnographic collection. On the one side it may be seen that two hordes related in speech have entirely different ethnographic characters, while, on the contrary, the industries of two may agree while genetically they belong to different stocks. This remark is very pregnant as regards South American peoples, and I shall seek on the basis of my studies of materials and literature to establish a correct theory concerning the ethnographic relationships of South America.

We must here examine the imitative instinct of men as a motive. Assume that different impulses and migrations of divers tribes having unlike ethnographic characters have brought them to settle near one another, one can recognize among most of these tribes a variation, through a series of years, of their ethnographic characteristics. They have become more or less assimilated in their mode of living and their ethnographic peculiarities. This assimilation, that is external likeness in type forms, may arise in different ways. If the tribes are inimical, then captured objects have influenced the technique, but if the tribes have entered into friendly commerce, then the possibility of acquiring by trade, tools, weapons, etc., is easily afforded. If they are brought into still nearer contact through the force of culture, through common acculturation, then the preservation of old ethnographic peculiarities in the tribe is rendered more difficult. Finally, among tribes that practice slavery there is still greater likelihood that these, owing to the

customary freedom of intercourse, would immediately impart their own characteristic forms to the peculiarities of their masters. But chief among these, that form which suggested itself as the fittest to adopt, and for which the locality and conditions supplied the necessary material would be most persistent. It seldom happens that proper material is procured from a distance through trade, or that any other material would be chosen than the one there in use for certain forms.

As the chart at the end of this article points out with respect to the distribution into ethnographic areas, there occur in the same tribe several separate types in close contact. This phenomenon is to be referred back chiefly to a certain persistency with which favorite old time forms hold on. This attachment to the ancient is very frequent on types that are completely changed through assimilation, still showing small idiosyncrasies or added decorations and so on, so that it is possible through these marks to obtain a glimpse backward on the original form. Frequently, through trade or capture, certain objects or weapons pass immediately into the employ of the new owner and are more widely diffused in association with the old forms. Especially in these inquiries in which several tribes are brought together in comparison is an association of this kind noticeable, but apparently comparison of different forms is possible only when a tribe has been split into several parts and each one has borrowed on other soil different customs and forms from neighboring tribes. These tribal divisions have then had an entirely different ethnographic development. Do we find among a group of originally diverse tribes, which have acquired through assimilation special ethnographic characters, a people with entirely different characteristics, then we are able to conclude that either this people remains out of contact with surrounding tribes or has just come there.

This ethnographic association would differ perhaps according to the choice of the object taken for the classification: at least my investigations lead to this result, whether we select the bow or the arrow as object of comparison. But a certain analogy is to be recognized in all grouping of this sort. For an ethnographic classification all the tribes studied should be regarded from the same point of view, namely, that the object selected shall be common to all.

As is known, the entire population of South America, originally depending on natural conditions, have been hunting peoples, and the greater part of them have held on to this manner of life. The hunting implement is then common to all. Now we find among the different tribes generally various methods of capturing animals. One employs the blowtube, the second a sling, the third a bola and a lance, but all have as the chief weapon the bow and arrow, which even the gun can not supplant, because the noiseless shooting of the bow does not frighten the game. Only the tribes of the Pampas, who since the influx of the Spaniards have taken up with the horse, have more and

more given up the bow, since as riders they can not conveniently use it. In fighting on foot at the time of Dobrizhoffer the bow was always the favorite weapon. Also the tribes that are now completely sedentary, which practice hunting along with agriculture only for amusement, exercise still the greatest care upon the preparation of this weapon and know how to use it with skill. In their sagas the bow and the arrow still play an important role. They are regarded almost as sacred and are frequently used as cult objects. If a people through constant association with culture exchanged their bows and arrows for other weapons, then the children kept up the old reminiscences and held on to the bow and arrow as playthings. We can thus appreciate the interest which a South American Indian feels when foreign bows and arrows are brought to his notice. He is accustomed to recognize the tribe by its arrow. I therefore indorse the position of Von den Steinen[1] when he says, "just as in comparative philology, a comparative arrow study may be conducted," as a rule for the resulting ethnographic grouping. This position has full force only when the difference of time between the arrival of different collections is taken into consideration, since, as has been already said, the ethnographic characteristics have been subject to great variations.

It can not then be wondered at that in the general distribution of bows and arrows so great a diversity of form exists, which makes possible a grouping for a fundamental study. This grouping demands again the separation of forms according to specific marks of structure. Of great importance in the distribution of the arrow appears to be the feathering, which seems to be capable of unlimited variation. There may be also bestowed a great deal of care on the fastening of the feather, on the wrappings of the shaft with thread, or upon the manner of fitting the feather. Moreover, the wrapping of the feathered end or shaftment offers excellent opportunity to preserve certain textile patterns, perhaps the one remaining survival of the old tribal peculiarity. Besides the feathering, the fastening of the point to the shaft, or of the point to the foreshaft, affords a safe datum for discriminating. The shape of the point also furnishes a guide for differentiations, however generally the varietal marks of the point and shaft adjust themselves with those of the feathering, so that the last may be taken as a basis for classification. The dimensions of the arrow are not directly useful as a means of separation, although individual tribes are characterized by the measurements of their weapons. Yet there are not seldom within a single tribe differences of half a meter in the lengths of the same sort of arrow. The choice of material depends chiefly on natural surroundings which a tribe encounters from place to place. It could, therefore, through identification of material and the botanical proof of the source of a plant, be shown that an arrow belonged to a certain group; unfortunately this is not possible where accurate data

[1] Unter den Naturvölkern, Central-Brasiliens, page 229.

concerning the material are not given by the collector. Only single types like the Chaco arrow may be recognized through the material. In the classification of bows through the cross section the material would be of weight.

Before offering some remarks on the characteristics of bow and arrow types by regions, I shall seek briefly to describe South American bows and arrows as a whole.

Unlike the North American bows, which are generally small and often made up of parts differing in material joined together, the South American bows are all self-bows, that is, they are made of a single piece. For the most part they are very large; only in the Guiana region and the northwestern lands, as well as in the South, the Gran Chaco, the Pampas, and in Terra del Fuego are smaller forms in use. A certain similarity of the Chaco bow with that of the northern Llano tribes, the Goajiro, is inexplicable. Further, in forest regions almost throughout, excepting Guiana, large, powerful bows are in use, while the smaller belong to open steppes. In this fact there is a contradiction to the affirmation of Ratzel concerning Africa, that the forest bows are smaller than the steppe bows, since the contracted forest prevents the use of the larger forms. On the contrary, among the Jauapery, who live in the forest region on the lower Negro, bows are found, according to Pfaff, 3 meters long. The South American bows are made with the greatest care, so that in the manufacture the peculiarities of the materials are utilized to their utmost extent. The form is, with rare exceptions, symmetrical. The curvature is not pronounced and symmetrical, but sometimes through a little bulge of the middle a slight double curve is effected. Bows are neatly wrapped with liana bast or with yarn and cotton string, partially, as a general thing, and frequently thus to old bows an artistic touch is given and beautiful patterns developed. Feather ornaments are also often added to the bow. The plain bows exhibit, as Ratzel has pointed out, a decided similarity with those of the Melanesians.

The size of arrows is naturally in relation with that of the bows. The steppe peoples and the Fuegians have the smallest arrows. They also exhibit much care in their finish, and adorn them greatly by means of wrappings upon the joints where the several parts are united. The arrows of the steppes are made especially with reed shafts having wooden points, those of upper South America have mostly in the reed shaft a fore shaft inserted, which carries the point.

The material of the shaft over the entire middle region is mostly the widely distributed knotless Uba reed (*Gynerium saccharoides*), and especially in the East the more slender Cambayuva reed. The reed shaft of the Chaco tribes is similar to the Cambayuva. Only among the Fuegians and a few other tribes in special kinds of arrows is wood used for shafts. The points are of wood, at times smooth and again with rows of opposite barbs, or from long, sharp splints of bamboo, from

bone, from spines of the ray fish and in later times of iron. Stone points were, indeed, originally in vogue over the whole area, and have held their own only among the most southern and the most northern tribes, Central Americans and Fuegians. Poisoned arrows are spread over nearly the whole forest region.

The different groups may now be characterized:

Bows in Central South America are of five different classes or groups:

Group 1.—Peruvian bow.—Rectangular or long elliptical cross section and almost always made of the heavy, black chonta palm wood. (Pl. LVII, fig. 1; Pl. LX, fig. 1.)

Group 2.—North Brazilian bow.—Semicircular cross section, characterized by the material, a reddish brown, smooth, leguminous wood. (Pl. LVIII, fig. 10.)

Group 3.—Guiana bow.—Small with parabolic cross section for the most part and a channel along the outer side. Made from a dark-brown wood. Between the north Brazilian type and the Guiana type there is an intermediate form.

Group 4.—Chaco bow.—Round and beautifully smooth exterior, made from the red Curepay acacia.

Group 5.—East Brazilian bow.—Distinguished by the choice of different woods. The type is separated into two subgroups, which at the north have their connecting link in the Shingu bow and at the south in the Kameh bow. The western class has been developed out of the smooth, strong wooden bow of the Bororó, having cross section, and wrapped with "cipo," a liana bast. The eastern subgroup is marked by the black Airi palm wood, in the southeast less carefully made by the Puri and Botocudos. On the contrary, in the Caraja bow (Pl. LIX, fig. 1) of dark-brown palm wood it has reached a high development, which still survives in the Shingu bow (Pl. LVII, figs. 1, 4, 7), the intermediate form between the eastern and the western subgroup. To the eastern subgroup belong the majority of the Ges tribes, while the western subgroup finds its greatest extension among the Tupi tribes of Paraguay.

Outside of this group stand the Mataco bow, the Fuegian bow, and the Central American bow, which are not considered here.

The types of feathering are as numerous as the bow types, and may be briefly characterized as follows:

Feathering of South American bows.

1. *East Brazilian or Gez-Tupi feathering.*—A widely separated group, which, like the east Brazilian bow group, extends over the entire eastern Brazil as far west as the Paraguay and the Shingu. Two feathers unchanged, seldom halved, are fastened at their upper and lower ends to the shaftment opposite each other with thread, fiber or cipo bast. Frequently these wrappings are laid on in patterns or have an ornamentation of little feathers added. (Pl. LIX, figs. 8 and 9.)

2. *Guiana feathering.*—Small, and carefully laid on. Two short half feathers are bound to the shaft in different places with seizings of fine thread. The shaft has always a nock piece to fit against the stretched bow string in shooting. An account of its distribution and of the footing or nock piece will be given further on.

3. *The Shingu sewed feathering.*—Two half feathers stitched to the shaft opposite each other through perforations. The ends are seized fast with plain or patterned lashing. (Pl. LVII, fig. 9.)

4. *The Arará feathering.*—Two long half feathers, which, in addition to the end seizings, are held down by narrow wrappings of thread at short distances apart. At the nock the wrapping is done in beautiful patterns. (Pl. LVIII, fig. 14.)

5. *The Mauhé feathering.*—Like the east Brazilian feathering, has two entire feathers bound on above and below. At the base of the shaft, however, a nock piece or footing is set in. (Pl. LVIII, fig. 13.)

6. *The Peruvian feathering.*—Constitutes a little group on the Ucayale and is quite like the east Brazilian on the whole.

Perhaps the Mauhé feathering, as well as the Peru wrapped feathering, belong genetically together with the Tupi feathering in the east Brazilian group. By this is strengthened the hypothesis of Von den Steinen and Ehrenreich that the west and the central Tupi wandered to the westward and to the Amazon again as far as the Tapajos and Shingu. Also on the Tocantins, on whose lower waters Tupi tribes have settled, are found arrow forms like to those of the Mauhé.

7. The great group of Peru cemented feathering includes two divisions:

a. The northern, belonging to the Amazon region, which falls into subdivisions according to the presence or form of the nock.

b. The southern, which embraces the anomalous Chaco feathering. (Pl. LVIII, fig. 15.)

The two feathers of the cemented feathering are separated from the midrib with only a thin portion of the quill remaining, bound fast to the shaftment in close spiral with thread or yarn, and to increase the hold on the shaft along the feather, the shaftment is covered with black or brown pitch.

Examining the chart of the geographic distribution of bow and arrow types, it appears that—

The division into ethnographic provinces by reason of the domination of certain forms, on the whole, has nothing to do with the tribal characteristics. As among the Bororo, starting out from an originally identical type, two entirely separate types succeed through different associations with other stocks;

The classification, furthermore, has not led to the same result for bows and for arrows;

Frequently from a bow an arrow is shot which has quite a different distribution from that of the bow;

But, yet, a certain analogy is discoverable in the two methods of grouping.

So the boundary lines of the enclave of east Brazilian feathering correspond in gross features to the boundary lines of the distribution region of the east Brazilian bow. Furthermore, omitting the region of the Chaco feathering, the region of the Peruvian bow is overlaid by that of the Peru cemented feathering.

The Guiana bow has about the same extent as the Guiana arrow; however, the southern boundary of the bow region lies more to the north than that of the feathering, which in several places overpasses the Amazon.

To these almost analogous groups belong a bow type which altogether detached from a feathering region on the north engrafts itself on the region of the Peru bow and the east Brazilian bow. Also, where the three chief feathering groups—the Peru cemented feather, the east Brazilian, and the Guiana—come together, three entirely separate feather types (Mauhe, Arara, and Shingu) have spread over regions whose borders intrude into one another.

This mixed area into which the characteristics of individual ethnographic developments have obtruded themselves is the Mato Grosso. We can from this realize what great importance the thorough exploration of this region possesses for the entire ethnology of South America, and I hold it, therefore, not fruitless if I seek before I describe clearly in a greater work the result of my investigations upon the collective material concerning the South American bows and arrows, to give, so far as it is possible, in this publication an ethnographic picture of the Mato Grosso.

The Mato Grosso is the highland in which several principal rivers of South America have their origin. While the Paraguay flows southward and furnishes, through its extremely fortunate advantages for navigation, the veins of commerce, the fountains of the most important affluents of the Amazon on the south spring from the neighborhood of the Paraguay sources, so that a lively commerce from the Amazon to the La Plata would go on across interior Brazil by water, if an impassable barrier to navigation between the northern incline of the Mato Grosso and deep water of the Amazon were not established by the waterfalls and rapids. Since, through the earlier expeditions on these rivers—Tapajoz, Shingu, Araguay, Tocantins—for the purpose of information concerning the feasibility of a good connection with the Amazons, no practical result was obtained, it is natural that general geographical knowledge about this region should have remained very meager up to this century. It was through the expeditions of Natterer, Castelman, Wedell, Martius, Pohls, Von den Steinen, and Ehrenreich that a glance was obtained at the natural relations of this area, and especially was it Natterer, Martius, Von den Steinen, and Ehrenreich who made themselves serviceable for the ethnography of the

northern Mato Grosso, and who have shown that the hindrances which the rapids in the streams mentioned opposed to general commerce are not so insurmountable that even great tribal migrations upstream and downstream can not be proved on ethnographic and linguistic grounds. The immense importance which the Mato Grosso possesses for the ethnology of South America here fully appears, and it follows hence that the knoweldge of the populations of the Mato Grosso must furnish the key for the entire ethnology of South America.

While the northern border is quite clearly fixed, on the east a limit is less sharply drawn, and the transition to the highlands of Goyaz passes only gradually through separate detached elevations. The sources of the Araguay are to be attributed to the Mato Grosso, while the Tocantins belong to the highlands of Goyaz. In the south the Mato Grosso slopes slowly toward the Paraguay basin. Let the boundary be the Serra de Cayapo, which extends from the western edge of the Goyaz plateau in a southwesterly direction to the Paraguay, and on the west side finds its continuation in a range of hills running in a northwesterly direction to the Rio Guapore. The alluvial lowland of the Paraguay is especially not to be reckoned with the Mato Grosso, though in ethnographic features it is not easily separated from it. In the southeast, the Mato Grosso is cut off from the Gran Chaco by the watershed mentioned, and on the west the Madeira furnishes the natural boundary with its forests, though these begin to appear already east of the Madeira. With exception of the woody river bottoms the Mato Grosso is a pure prairie region, which stretches away between the north flowing river perhaps still farther than the north border of the Mato Grosso.

It is clear that the Mato Grosso in its central location before mentioned, endowed with extremely favorable natural conditions, must have played an important rôle in the history of the South American peoples. Of all the events, however, of which the Mato Grosso was the theater of action nothing more is known. Only from traditional relations of a few tribes or from the narratives of colonists may the latest migrations and invasions be followed. It is therefore not possible from the present condition of knowledge to draw a correct ethnographic picture of the original divisions and dispersions of the populations. We are able from the comparison of materials in museums to gain only a foothold for the knowledge of prior wanderings. The inquiry how far these assumptions can be of use for illuminating the theory of migrations of the Ges, Tupi, Carib and Nu Arawak families by means of comparative philology, proposed by Von den Steinen and Ehrenreich, lies outside the borders of this treatise and will be examined later.

The ethnographic picture of the present Mato Grosso shows, as may be seen from the chart of distribution, a division into four, perhaps three, regions when the arrow or the bow is used as material for comparison. Each geographic region is characterized by the predominance of a fixed tpye, which is peculiar to one of the above-mentioned ethnographic regions. In both classifications the two great areas of east

Brazil and the Peruvian type hold good which have certain analogies in their own borders. Some of the chief divisions in the Mato Grosso seem accidental to the Shingu drainage. Therefore, in accordance with the bow types, the Mato Grosso is divided into a west and an east half. The north Brazilian bow region does not overlap the Mato Grosso. When arrow types dominate the divisions two other distribution areas are revealed, in one of which the wrapped or sewed feathering prevails, as the peculiar Mato Grosso feathering may be termed, while the borders do not extend beyond those of the Mato Grosso. The area of the Arara feathering lies within the eastern part of the region of the Peru feathering; furthermore, the Mauhe feathering extends its influence on the northwest of the Mato Grosso. In the west Mato Grosso occur also the cemented, the Mauhe, the Arara, and the sewed feathering. This may be best characterized as to the mixed region, set forth as follows:

1. *Eastern and southern region.*—East Brazilian feathering.
2. *Central region.*—Sewed feathering.
3. *Western region.*—Mixed: Cemented, Arara, Mauhe, and sewed feathering.

Considering the bow in the same connection gives the following group:

1. *East Brazilian bow with East Brazilian feathering.*—Araguay and southern Mato Grosso.
2. *East Brazilian bow with Shingu sewed feathering.*—Shingu and West Bororo.
3. *Peru bow with feathering of mixed areas.*—Tapajoz.

This grouping is naturally to be taken *cum grano salis*, since transgressions and intrusions occur in individual cases.

In the following consideration of single stocks or tribes it will not always be possible to hold strictly to the plan, while this arrangement, which throws upon the screen a complete ethnographic picture with natural coherence often, as will be seen of the Bororo, must point out the originally component parts of a stock, on account of the differing developments of its ethnographic characters. In order to set forth genetically the types resulting from the original type an assembling of the parts is necessary in the discussion.

Let us begin with the tribes of the upper Shingu, which belong collectively to the area of the East Brazilian bow with sewed feathering. These tribes, which have been known to us only a short time through the two Shingu expeditions of Von den Steinen, belong, according to his investigations, to different linguistic families, to wit:

	Linguistic families.
Baccairi, Nahuqua	Carib.
Aueto, Kamayura, Menitsaua	Tupi.
Mehinaku	Nu-Arawak.
Suya	Tapuya or-Gês.

This commingling of tribes, belonging to different stocks in the comparatively narrow space of the upper affluents of the Shingu, Kulisehu, Batovy, and Kuluene, furnishes the best example of how, through long contiguous dwelling, national peculiarities are obliterated and a new common type takes the place. The bows and arrows of these stocks differ only very little from one another, but together very much from those of the stocks of the lower Shingu; for example, from the Yuruna, of whom they have no knowledge, on account of the rapid streams difficult to pass. Among these, it will be seen later, the East Brazilian feathering unites with the Peru bow, a circumstance which witnesses in favor of the Von den Steinen theory of the migration of the western Tupi.

If the Upper Shingu tribes be kept solely in view, without regarding small differences, the following statements may be confirmed:

To all of them the bow and the arrow are common, while other weapons, such as the throwing stick and the club, appear only among isolated tribes.

The arrows, as well as the bows, are universally beautiful and carefully wrought, from which Von den Steinen draws the conclusion that they indeed, as hunting peoples, had also an irregular kind of sedentary life, and that they, notwithstanding that the hunter stage is always more and more being supplanted by agriculture, have not become negligent in the manufacture of hunting implements. This rests chiefly upon the exalted position which the bow and arrow holds in their tradition. He mentions of the tribal history of the Baccairi, among others, that the culture-hero Keri had created the tribe out of different arrow reeds. (Von den Steinen, op. cit., 228, 379.)

Von den Steinen says, "the length of the bow reaches 220 to 250 cm." (Pl. LVII, figs. 1–7). The yellow wood is furnished by the Arata tree tecoma, etc. Dark-brown palm wood is often found among the Aueto and Kamayura tribes and among the Tupi stock, whose bows are wound with cotton wrappings in a sort of staircase pattern, a decoration widely distributed in South America. The cross section of the bow is about circular and it tapers toward the end, becoming more elliptical. The ends are somewhat rounded for the reception of the bowstring, running to points. The bowstring, twisted from the bast of the tucum palm, is looped on at one end. It is knotted around the other end and is extended along the back, becoming smaller and smaller, and is made fast around the upper limb, about two-thirds the height of the bow. The curvature of the bow differs and often there is more than one curve. A single slight curve is rare and only to be found among the Baccairi and the Nahuqua. The Aueto and Kamayura have slightly double-curved bows, with ends bent back. The bows of the Baccairi, Trumai, and the palmwood bows of the Aueto and Kamayura show a bend of the limbs in an opposite direction.

On a bow of the Kamayura and two of the Baccairi are tight leather rings stretched over the limbs, a custom which is also to be seen upon

the bows of the Sokleng of southeastern Brazil. (Pl. LVII, fig. 7.) That different ways of bending the bow are customary close together in the same stock is not to be admitted; it is more likely that bows whose exact origin is not fixed might have been scattered by the lively barter on the Shingu.

The arrows appear to have less dispersion as trade objects, which again has its explanation in the fact that the arrow is esteemed as a characteristic of a tribe, and for that reason is less communicable to another tribe. Therefore we see among the most southern tribes—Baccairi, Nahuqua, and Aueto—no arrow with Cambayuva reed shaft; for, as is known from the tribal history of the Baccairi, these are made of Uba reed, a characteristic also of the Baccairi. This reed, in order that the natives may not be compelled to get it from far away, is planted in great patches in the river Batovy. (Von den Steinen, op. cit., p. 210.) The northern tribes, on the contrary, have substituted for the Uba reed at times the Cambayuva reed, which, among the Yuruna, furnishes the only material on that side of the rapids. The use of the Cambayuva reed, which predominates on the Tapajoz and the Araguay, appears, from the latest information, to have arrived first upon the Shingu: at least other peculiarities permit the conjecture of an influence from the East.

Different kinds of points are to be found among nearly all the tribes of the Shingu. The simplest is a smooth-pointed piece of wood driven into the end of the reed shaft. This form is common to all stocks, as is one with a middle piece (foreshaft) fastened on with pitch and pointed with the beveled humerus bone of a monkey. (Pl. LVII, fig. 8). Finally there is found, as will be seen also among the Bororo and Guato, the style that belongs to the East Brazilian group. A point with a barb or hook, effected by means of a double-pointed piece of bone laid in the hollow outer end of the fore shaft (compare Pl. LIX, fig. 6), wrapped with thread and pitched, is used among the Caraja on the Araguay, as well as in Western Brazil and Guiana. It is found among the Aueto, Kamayura, and Trumai. On one side of the smooth wooden point of the Baccairi and the Nahuqua arrow 10 cm. long a barb is provided, by wrapping a little tooth or jaw spine of the ant bear. (Pl. LVII, fig. 14.) This practice is also a peculiarity of the Caraja. The use of the spine of the ray is also in vogue here. (Compare Pl. LIX, fig. 13.) Von den Steinen denies that the Shingu tribes, excepting the Yuruna, used the barbed wooden point; yet there is in his collection a specimen from the Kamayura (Pl. LVII, fig. 12), which exhibits exactly this type of the Shingu arrow. This point, moreover, which is found abundantly on the Gez arrows, must have come from the east. The Suya and the Trumai use in war and in chasing the jaguar arrows with long bamboo knives bound to the end of the wooden fore shaft, which are manufactured on the Shingu only by these tribes (Pl. LVII, fig. 2). Of this pattern, moreover, there is found an example among the Kamayura. The Baccairi collection contains also

an arrow with bamboo knife-blade point. (Pl. LVII, fig. 13.) However, this point deviates from that of the Suya in form, and resembles much more that of the Yuruna or of the Tapajoz region. It is strongly probable that the arrow came hither from the Yuruna, but perhaps it is a reminiscence of the earlier home of the Baccairi upon the Arinos.

Of the feathering I have briefly written in the general classification. (Pl. LVII, fig. 9.) Let it be here simply remarked that the variegated feathers of different birds are bound on in spiral wrappings of 90 degrees. At the nock end is generally found a wrapping of thread in staircase pattern as on the Aueto bow, which is laid over a ring cut from the bark of the wambi (Philodendron), to which is also fastened a little ring of red feathers. Sometimes the feathers are wanting, and only the wrapping with the bark ring and feather tuft remains. The nock is small and round.

On some arrows of the Suya, who must have wandered, according to tradition, from the great stock of the Gez, on the Araguay and Tocantins to the west as far as the Tapajoz and back to the Shingu, occurs also east Brazilian feathering. Both wrapping material for feathers are made from white bast. Moreover, on the tip of the shaft is fastened a tucum nut (Pl. LVII, fig. 10) bored with holes, by means of which it sends forth in flight a clear sound. This toy is in vogue on the Tocantins as well as on the Tapajos, and also among the Arara on the Madeira; it is also spread among the Suya from east to west. A circular band of color on the shaftment of some Baccairi arrows, as well as the custom all along the Shingu of binding the shaft and fore shaft with windings of bast, hints at Eastern influence.

In briefly recapitulating we must recognize decidedly an influence from the East. It appears, moreover, that the more southern tribes had been less overcome thereby. Upon the relationship of the eastern Baccairi to the western Baccairi on the Arinos the language must be the decider.

Furthermore, among the tribes of the Upper Shingu still in use among the Cayapo (Pl. LIX, fig. 17), is found the sewed feathering, which, according to the report of Von den Steinen (op. cit., p. 155), has intruded itself from the majority of the tribes on the Araguay and Tocantins to those of the upper confluence of the Paranatinga, belonging to the drainage of the Tapajoz, in friendly relationship with the Baccairi and Nahuqua. However, since they have preserved in arrows and bows almost completely the characteristics of their principal tribes, it will be more seasonable to treat of them in the discussion of the eastern groups. Outside of tribes of the upper Tapajoz, treated of in that which follows, who in addition to other styles possess the sewed feathering, it is interesting to find in the Marine Museum at Rotterdam arrows with sewed feathering from the lower Tocantins, from the Tembe, and from an unknown tribe on the mainland opposite the Ilha de Arco. Perhaps it was from this unknown tribe that the Tembe on the other

side of the Tocantin received this technique, a tribe from the Shingu, which at the beginning of the century supplanted the Carib tribe of the Apiaka. This phenomenon is more interesting because through it the center of radiation of the sewed feathering is fixed on the head waters of the Shingu or the Paranatinga, and perhaps this feathering can be fixed as specially Carib. Therefore the circumstances bear witness that on the Madeira, among the Arara, who are to be assigned to the Caribs, the sewed feathering might first occur; still, even as easily it could have come to this tribe through the medium of the Apiaka of the Tapajoz, for the typical Arara feathering is also found again among the Apiaka.

Older collections from the Shingu perhaps will furnish information on this topic. Still, the possibility of finding such is far from certain, since the Shingu tribe, up to a short time ago, were wholly unknown.

A good transition from the central group to the westward or mixed group is furnished by the settled Baccairi belonging to the Shingu branch of the Baccairi, who lead a peaceable existence as agriculturists in the area between the Paranatinga, the Cuyaba, and the Arinos, in slight contact with their culture. As we know from the accounts of the Baccairi collected by Von den Steinen, both divisions were originally united near the falls of the Paranatinga, from which, accidentally, in the middle of the last century, one part drew away upon the Ronuro and Batovy to the Kulisehu, the other settled in the above-named region in a southwestern direction. We possess some arrows of these settled Baccairi in the Vienna museum, collected by Natterer in 1827 from the Arinos. (Pl. LVIII, fig. 15.) I was surprised to see among them Baccairi arrows, since this type deviated so much from them in the Von den Steinen collection, so well known to me, and at once, by nearer comparison, I could prove that they belonged there. With exception of the point, they pertain to the group of cemented feathering, and indeed to those in use on the Tapajoz and on the Madeira with pointed notches or barbs cut out and for the most part overlaid with reddish brown pitch. The well-known Uba reed of the Shingu is here replaced by the lighter and thinner Cambayuva reed. Von den Steinen says (op. cit., p. 229), "the settled Baccairi have, since they became acquainted with muskets, given up the Uba reed in general use on the Upper Shingu and possess now, if not purely boys' arrows, at least small arrows in comparison with those on the Shingu." I refer this change in the choice of material and the turning to another technique not to contact with culture but rather to association with the tribes of the Arinoz and Tapajoz. Any affiliation with the kindred tribe on the Shingu later has demonstrably not taken place. This tribe was known to the settled Baccairi only through the tribal history. Assimilation with the Tapajoz tribes could for that reason go on more easily. That the western Baccairi originally and indeed also down to the separation have used the Uba reed is proved by the Baccairi tribal history con-

cerning the plant. That the sewed feathering is peculiar to the whole nation and was not first adopted on the Shingu by the eastern Baccairi is shown by the fact, as will be seen later, that the western Bororo living at the head waters of the Paraguay, who perhaps at the same time have turned away from their eastern brethren on the Lorenzo (Pl. LVIII, fig. 17), in twenty years had adopted the sewed feathering and in some measure had modified it. But the then wild, contentious hordes could have been in contact only with the still united Baccairi, since the eastern Baccairi are now too widely separated from the western Baccairi to be in touch with these. The northwestern neighbors, the Pareci, who now practice the sewed feathering, can not be considered as middle men, since at that time the Pareci did not have the sewed feathering, while already the Bororo possessed it. While also the western Baccairi prove their ethnographic affiliation with the Tapajoz region by the Cambayuva reed and cemented feathering, they betray their relationship with the wild Baccairi of the Shingu only through the point on the arrow. Both points have been ascribed already to the Shingu as characteristic, the bone point from the humerus of the monkey stuck on the foreshaft (Pl. LVII, fig. 8), and that with the zygomatic process of the ant-bear (Pl. LVII, fig. 14) bound as the side of a palm-wood point about ten centimeters long, which, as was seen already, is on the Shingu peculiar to the two Carib tribes, the Baccairi and the Nahuqua.

Concerning the bows of these Baccairi, unfortunately, nothing is known. Von den Steinen reports only that they are smaller than those on the Shingu.

From the tribes of the Tapajoz region, which is only partially known to us, there are in many collections pieces whose exact location must first be fixed by comparison. The Natterer collection in Berlin has also thrown some light on this region. As was already brought forward and is apparent on the chart, the tribes of the Upper Tapajoz represented in the collections, in addition to other forms of arrow, have those with sewed feathering. We assumed already that the point of diffusion of the sewed feathering on the Shingu or of the united Baccairi might have been on the cataracts of the Paranatinga, and shall therefore seek to find out the path along which it arrived at the tribes settled on the Tapajoz and Madeira.

Eastern influence in the Tapajoz region appears first to be a secondary consideration. The principal migration has taken place from west to east. Which one has been the original type of bow and arrow in the Tapajoz region is no longer determinable on account of the diversity of types at present existing side by side. As may be seen upon the chart, there can be demonstrated by the material on three or perhaps four sides an acculturation of the ethnographic characteristics of the Tapajoz tribes. The Tapajoz region upon the chart is entirely surrounded by the region of the Peruvian cement feathering, and the

western Baccairi mark the farthest projection of this ethnographic development from the west. The cement feathering, which has wandered from the west to the east, whose starting point is to be sought in Peru, has undergone many variations in its long journey to the Tapajoz. In the Mato Grosso, coming westward, is found the type of feathering with the notches cut out, on which generally a little bunch of red feathers is fastened. (Pl. LVIII, fig. 15.) The Madeira River is approximately the boundary between this and a western group, where the cement feathering comes in without notches, but with bands of network woven on the shafts. In the great Parentintim tribe these groups touch one another. A common peculiarity with the cement feathering, and also with the Arara feathering, is a decoration of the shaft by means of small encircling bands made of white quill, which explains the wrapping in stepped winding of cotton, previously mentioned as on the Shingu. (Pl. LVIII, fig. 14.) These quill rings are to be found among all groups of the cement feathering, and have perhaps served as suggestive methods for the bast rings on the Shingu sewed feathering. The Arara feathering appears to have derived the quill ring likewise from the pitch feathering, as will be seen. It is in this manner further perfected through an ornamental weaving in black and white strips of quill. (Pl. LVIII, fig. 17.) The notch has been here copied from the arrows with cement feathering influenced by the Arara type, and is cut out narrow and with a pointed angle.

Generally in this Madeira-Tapajoz region a large, broad, bamboo point, 30 to 40 cm. long, is distributed, which on one side is cut into an angle lying in the long axis, and is hollowed out on the under side so that the cross section shows a concavo-convex outline. (Pl. LVIII, fig. 16.) The foreshaft, upon which the point is fastened by means of a wrapping of thread, extends somewhat above this wrapping and is set at its other end, which is pointed, into the bamboo shaft. This point, which differs from the bamboo points of the western region as well as from those of the Shingu, is found outside of our region also among the Arawak tribe and the Juberi, on the Purus. It is well to mention that this point, like the cement feathering of the Madeira, has gotten as far as the Tapajoz.

Likewise a peculiar, barbed point, which is formed by a spindle-shaped bone, 10 to 15 cm. long, pointed at both ends and seized at its middle upon the upper end of the foreshaft, appears to have come among the Apiaka and Mauhe from the Madeira in abundance. (Pl. LVIII, fig. 19.) Thence it spread among the Parentintim, and from them is to be found among the Manaos on the lower reaches of the Madeira. In a remarkable way it makes its appearance also on the Tocantins, where exists also a kind of Mauhe feathering. If I had not found examples of this in different museums labeled Tocantins, I should have attributed them to the Tapajoz area.

Of the distribution of the Arara and the Mauhe feathering mention

has already been made. (Pl. LVIII, figs. 13 and 14.) With the Arara feathering, as well as with the cement feathering, the pretty and well-known stepped wrapping is chiefly associated, which statement applies to the feathering as well as to the uniting of the shaft to the foreshaft.

The Mauhe feathering, which is perhaps a Tupi feathering modified through the Guiana type, comes into consideration here only so far as Mauhe arrows have been found among the Apiaka and the Mundrucu.

In contradistinction to the Shingu region we here find the Cambayuva reed distributed throughout the upper basin of the Tapajoz and the Uba reed throughout the lower.

In comparing collections at my command from the Madeira and the Tapajoz tribes, it became unexpectedly possible to recognize the present position of the unique metamorphosis of the type caused through foreign influence. In the Natterer collection of 1827 it may be observed that on the Tapajoz the cement feathering appears among the Apiaka, Mundrucu, Baccairi, and Pareci. It is now assumed that on account of the similarity of form among the Parentintim and the Apiaka the type of cement feathering, together with the well-known bamboo and bone points from the Parentintim, came last to the Apaika, and from these went downstream to the Mundrucu and upstream to the Pareci and Baccairi. Upon the relationship of these tribes to one another little is known; only, Martius has said concerning the warlike Mundrucu and Apiaka, that enmity and friendship alternate. (Beiträge zur Ethnographie Sudamerikas, pp. 211, 391.) It is easy to conceive that the Apiaka came upon their long canoes into contact with the Pareci and the neighboring Baccairi dwelling at that time still further northward. (Ibid., 206.) In 1828 the gold prospector Lopez must have camped with some Baccairi under escort of Apiaka Indians on the Peixes River, an adjoining stream to the Arinos. At any rate the occurrence of the sewed feathering among the Apiaka hints at communication with the Baccairi. (Von den Steinen, op. cit., p. 388.)

In the arrows of the Apiaka at that time, eastern influences had been amalgamated with western, and sewed feathering and Baccairi points had been united with cement feathering and Madeira-Tapajoz points by commerce. The little barb bound diagonally on the side of the point, peculiar to the Baccairi, is here abundantly represented by a small palm-wood spine (cf. Pl. LVII, fig. 14), the long palm-wood point at times greatly thickens in the middle, as is customary on the Ucayale. Further, there is to be found among the Apiaka an arrow with Mauhe feathering and Tapajoz bone point, but with a Cambayuva shaft, impracticable for this kind of feathering.

Upon the Pareci arrows with cement feathering is seen, along with the bamboo point, also received from the Apiaka, a long wooden point with two sharp teeth or barbs set opposite, projecting at different distances outward, and striped throughout its entire length with clear brownish-gray poison. The occurrence of a poisoned arrow on the

Upper Tapajoz is very surprising, and it must be assumed that this arrow came either from the Mundrucu or from a tribe settled westward on the Madeira, since outside of the extinct Tapajoz, who, according to Acuña's account, possessed poisoned arrows. (Martius, op. cit., p. 382, 388.) On the Tapajoz River only the Mundrucu knew of this practice. The Parentintim have a similar toothed projection on the foreshaft of an arrow with bone point.

Along with the cement feathering is found among the Pareci and the Cabischi related to them the Arara feathering. Still, it is here noticeably smaller, and there is wanting the stepped weaving customary among the Arara. Connected with it is associated also the bamboo point in use among the Arara. Since there is found in the Natterer collection among the northern Tapajoz tribes no Arara feathering, there must be assumed a direct contact of the Pareci or Cabischi with the Arara in the south who must inhabit the still unknown region between the Juruena and the Madeira. The variation which the Arara feathering has undergone at the hands of the Pareci is thus accounted for, if the differentiation had already sufficient time to take place before the exploration of Natterer.

The feathering of the Cabischi arrow is like that of the Arara in length, but shows at the butt end a very carefully cemented wrapping with fine bast (Von den Steinen, op. cit., p. 426), which, as will be seen, exhibits a similar workmanship to that of the Bororo on the Cabaçal. As generally happens, the bamboo point has another form here. It runs to a sharp tip with flat concave section and has at the inner end edges cut oblique. According to the account of Captain De Motta (cf. Pl. LX, fig. 17), in the year 1886, the Pareci have the same weapons as the Cabischi.

In the arrows of the Mundrucu, living to the north of the Apiaka, meet and cross the types of the cement feathering of the Apiaka and the Mauhe feathering. It is merely a poisoned arrow with a fish-spine point projecting forward, which calls to mind similar pieces on the Upper Negro, but shows the usual cement feathering. The Mundrucu must first have learned in modern times the use of arrow poison, and this they did not invent themselves, but borrowed it from the northern neighbors. (Martius, op. cit., p. 389.)

To discuss the arrows of the Mauhe, living entirely outside of the Mato Grosso, is beyond the scope of this paper. They also have been strongly influenced by Madeira forms. So rest the accounts of 1827.

There are outside of the Natterer collection two smaller ones of whose date of acquisition nothing is known, but from a comparison with that of Natterer it appears to have been secured later. One of these collections in the British Museum has the mark "Apiaka, Rio Tapajoz below the mouth of the Juruena." The other, in the museum at Stockholm, acquired on the coast from the Brazilian General Silva da Castro, has no data of locality, but is to be ascribed also to the Apiaka.

Since the arrows in the British Museum represent exactly the type of Natterer's Arara, and particularly his Tora arrow, they may, provided the label Apiaka is to be retained, have come over directly from the Arara to the Apiaka A characteristic of the Arara arrows is, besides the feathering, the frequent occurrence of beautifully toothed bamboo points (Pl. LVIII, fig. 17), which are also to be found among the Juberi on the Rio Purus, and in somewhat modified forms among the Cashivo on the river Ucayale. A more striking peculiarity is the decoration of the shaft by means of ornamental wrapping, carefully laid in strips of white and black quill. Among the Arara the setting of a Tucum nut (cf. Pl. LVII, fig. 10) on the shaft is practiced, and perhaps came to them from the Tapajoz, where the Suya got the idea from the eastward. The Tora arrows, resembling in essential particulars those of the Arara, have, however, adjoining the quill work a painted ornament (Pl. LVIII, fig. 18) on the wrapped tang of the bamboo point, which also the arrows of the Parentintim show abundantly.

While these arrows exhibit, indeed, the pure Arara type and on that account do not leave the indication of locality free from objection, the unmarked arrows of the Stockholm Museum with greater certainty may be ascribed to the Apiaka. They show partly a union of cement feathering with the most general fashion of the Arara arrow; are, in fact Arara arrows passed over to the Apiaka type. One arrow displays the variety of sewed feathering discovered by Natterer.

If we now study the boys' arrows in the Von den Steinen collection of 1888 (op. cit., p. 433), belonging to the Pareci tribe who, according to that author, have exchanged bows and arrows for muskets and given the former to boys for playthings, we shall see also the variegated sewed feathering.

It appears also that this, which, indeed, long before the beginning of the century, had gone westward as far as the Arara tribe in a somewhat simplified form first, in much later times had found its way among the northern tribes of the Tapajoz.

We may now bring together briefly the results of studies upon the Madeira-Tapajoz region. The bow and the arrow types of the Tapajoz tribes show preponderating westerly influences, which these received from the Parentintim and the Arara by way of the Madeira. The first demonstrable intrusion, the migration of the cement feathering, came upon the Apiaka from the Parentintim. Thence it found wider distribution in the Tapajoz region. Perhaps at the same time the sewed feathering of the Baccairi, somewhat varied among the Apiaka, extended to the Arara, and a third stream moved along from the Arara to the Cabischi and the Pareci. Later came also the Apiaka into direct contact with the Arara and received their type unmodified. The sewed feathering meanwhile intruded southward and was received by the Pareci. The working in of the Mauhe type is only of a secondary importance.

From other tribes of the Tapajoz region, which are known only by

name, we possess no collections. Of the Cayabi, near neighbors of the Baccairi on the Rio Verde, Von den Steinen says "that they use arrow shafts of Cambayuva reed." (Op. cit., p. 392.)

The distribution of the bow types is very simple in the Tapajoz region and shall be touched on only briefly.

The Museums possess bows of the Mauhe, Mundruku, Apiaka and Pareci, and some with the general label Tapajoz.

Martius describes (op. cit., p. 203, 401) two different bow types among the central Tupi, to which stock belong for the most part the tribes on the Tapajoz. "They shoot long arrows from immense bows, often longer than a man, made from the black wood of a palm tree or the red wood of a mimosa, whose strings are twisted out of Tucum fiber or cotton." The bows from black palm wood belong to the Peru group, and are represented on the Tapajoz by Apiaka and Pareci examples. (Cf. Pl. LVIII, fig. 1.) The bows made of red leguminous wood, pao d'Arco of the Portuguese, with semicircular cross section are of the northern Brazilian type and here occur among the Mundrucu and the Mauhe. They are, for the most part, manufactured by the Mauhe and brought to the friendly Mundrucu through trade. (Pl. LVIII, fig. 10.)

Martius met on the Tapajoz a chief of the Mauhe who brought out a bow of red wood to the Mundrucu and exchanged it for feather ornaments. (Martius, op. cit., p. 88.)

A bow 180 cm. long (Pl. LVIII, figs. 6–9) of dark-brown wood in the Copenhagen Museum with ornamented ends which exhibits an artistically carved human head having eyes inlaid with mother-of-pearl over which a line runs on both sides in a meandering pattern is most interesting. In cross section it belongs to the North Brazilian bow region. The peculiar ornament is found, moreover, on a war trumpet in the Copenhagen Museum which was found among the effects of the Prince of Nassau in the middle of the 17th century and of which Ehrenreich has given a short account in Globus. Furthermore, this same ornament is to be seen on two remarkable little boards in the Christiania Museum as well as on a club in the Martius collection in Munich, illustrated in Ratzel's "Volkerkunde" (11, p. 575). But in Vienna the label "Mundrucu" is upon a war trumpet which had been overlooked having the same ornament. The decorated end is bored through for the fastening of the cord, a fashion entirely out of vogue now in South America. The cord is a thick twisted gut string. In the middle or grip the bow is whittled on the inner side for better handling.

From the Pareci two bows are in hand, one from the Natterer collection, the customary Peru bow made from black palm wood, the other, a boy's bow, also made of black palm wood, brought by Von den Steinen having the North Brazilian form. Here occurs a rare instance in which a tribe adopts a foreign form without using for it the customary material. The form of the North Brazilian bow has either gone to the Tapajoz outwards through the Mauhe to the Pareci or been received from the Tora, from whom, as was seen, the painted ornament arrived on the

Tapajoz. Whether the road which the Peruvian bow took toward the Tapajoz is that of the cement feathering is not determined, since the only accessible Parentintim bow in the Berlin Museum shows angular edges, while the Apiaka and Pareci bows are rounded. Perhaps this has its origin among the tribes settled higher up on the Madeira who possess similar bows.

Having sketched in the foregoing pages the ethnographic characteristics of the Tapajoz region and recorded the ethnographic information concerning Shingu and Tapajoz peoples, I shall proceed no further among the Madeira tribes, since these indeed do not belong peculiarly to the Mato Grosso and are of interest only as they influenced the character of the Topajoz region. Upon the characteristic forms which the migration to the Tapajoz made necessary, communication has been made in the course of the foregoing narrative.

The Araguay region presents only pure eastern forms, so that here is exhibited a much more simple ethnographic picture. Bows as well as arrows belong to the almost united group of Eastern Brazilian bows and feathering. By the evidence of the Shingu tribes it could be emphasized that some arrows of the Suya, like those of the Yuruna of the lower Shingu, deviate very much from the Shingu type and belong to the eastern feathering group.

The Suya are as already seen, the member of the Ges or Tapuya stock most widely pushed to the west, and they have in spite of their long backward stretched road to the Tapajoz and to the Shingu, and in spite of the manifold contact with other tribes, held on partly to the old type, or after they had set their foot again on the Shingu adopted anew the eastern feathering.

The Yuruna, who, as is ascertained through Von den Steinen, are known through their travel downstream and possess not the slightest knowledge of the Shingu tribes, stand in more constant touch with the widely branched and extensive Caraja tribe, who control the region from the upper Araguay entirely to the lower Shingu and are the dreaded opponents of the Shingu tribes. Von dan Steinen found among the Yuruna Caraja prisoners as well as a club captured from this tribe, and further among the Kamayura of the Shingu a club and an arrow of the Aruma, an ethnographic horde belonging to the Caraja tribe. Moreover correspondences to the Caraja type were previously observed on the Baccairi arrows. The Yuruna live on the borders of the eastern and the western feathering and bow regions, and they have received from the western region the dark palm-wood bow and from the east the arrows. (Pl. LVIII, figs. 1–3.) The bow exhibits not the customary form on the Tabajoz, but resembles more that in use farther to the west, with sharp rectangular cross section.

Also this cropping out substantiates the theory of migration concerning the central Tupi; the stepped weaving is also found here. The arrows of the Yuruna have the Cambayuva reed shaft in vogue on the lower Shingu, upon which a wooden fore shaft is attached by means of

a wrapping of bast. The upper end is oftimes channeled, and in the cavity a double piece of bone is fastened by means of a wrapping of fine thread cemented over, after the customary manner on the Shingu (Pl. LIX, fig. 6). In another kind of arrows there is on the point of the fore shaft a long, similar strong bamboo point, with half moon, concavo-convex cross section tied on by means of neat wrapping of thread around the tang, and the fore shaft is packed in a furrow cut out.

The bamboo point resembles precisely in form the one mentioned as belonging to the Baccairi on the Shingu. (Pl. LVII, fig. 13.) Still a direct connection is excluded. Where the common origin is to be sought can not be conjectured. Also are seen arrows with a simple stick of hard wood sharpened and stuck in the front end of the shaft. The feathering is very similar to the Caraja style (Pl. LIX, figs. 8, 9); two whole feathers almost 20 cm. long, opposite each other, are wrapped fast to the shaft with thread in slightly spiral arrangement, and the points of the feathers stick out at the butt end in form of a tuft. The decoration of the lower part of the shaft, and much of the fore shaft with wide spiral and longitudinal lines painted in black and yellow lac-like colors, is also abundantly practiced by the Caraja. The nock, which is cylindrical on the Caraja arrows, is here, as on the Tocantins and Tapajoz, continued to a point.

The Caraja, whose linguistic affiliation with the Ges group is not yet made out, are, as Ehrenreich's collection proves, surely to be accredited to it ethnographically. Bows and arrows show the characteristics of the eastern type and correspond almost entirely with those of Crahaos and Chavantes, their eastern neighbors, belonging to the Ges or Tapuya stock. The predilection of the tribes belonging to this group for the use of bast for fastening feathers, fore shafts, and bamboo points, which is to be seen on the Shingu River, is also in bold relief in the Caraja crafts. The wooden point, with unilateral barbs, characteristic of the Ges of the southeast (cf. Pl. LVII, fig. 12), which had penetrated already to the Kamayura and arrived among the Suya, is not found among the Caraja. Only the arrow originating from the hordes of the Aruma, which Von den Steinen got on the Shingu, shows this Ges point.

The bow is beautifully wrought out of dark-brown palm wood and decorated with feathers and ornamental wrappings of thread. (Pl. LIX, figs. 1–5.) In the manipulation of the material, the circular cross section flattened occasionally on the back, and the peg-shaped ends characterize excellently the South Brazilian bow of the Botocudo and Puri. However, near the Caraja and thence to the Shingu and south to the Cayapo, it shows fundamental dependences on the bow types there. It is slightly bent, about 2 m. long, and strung with a strong cord twisted from threads, which is knotted on one end and on the other encircles the peg, then returns on the back of the bow about halfway, as was seen on the Singu, where it is made secure under seizings. The lower end of this wrapping is decorated with a compact layer of

leaves, held on by means of black cotton thread bound closely down. At the end of this bowstring, wound backward and colored with white clay, is a large yellowish-red bunch of feathers, bound on as ornament. Moreover, about both ends is wrapped a stepped pattern about 5 cm. broad. The decorations are frequently wanting.

The arrows are quite as carefully made as the bows. The shaft is of Cambayuva reed, and the fore shaft, of different kinds of wood, is frequently, as among the Yuruna, adorned with yellowish-brown or red lines and points in lac-like paint. Among the very diversely shaped points occur only two already known, the smooth wooden point and the short bone point (Pl. LIX, fig. 6) set in slantingly in the wooden fore shaft, which is common among the Yuruna and upon the Shingu. Frequently this bone piece is replaced by a fish spine. (Pl. LIX, fig. 13.) A peculiar point, which is made of a delicate cylindrical bone cut off obliquely at the outer end, is cemented upon the point of the fore shaft, reminding one also of a similar form on the Shingu, only there the barbs are wanting. Moreover, there are two noteworthy points of palm wood to be mentioned as peculiar to the Caraja. One of them, lanceolate, two edged, with an angle on one broad side and the other rounded. The second point is knife-blade shaped, with a somewhat serrate edge at the inner extremity of the edge. (Pl. LIX, figs. 11, 12.) Both call to mind similar southern forms among the Cengua tribe in Paraguay. A lighter arrow for small game is made wholly from a piece of Cambayuva reed whittled to a point. (Pl. LIX, fig. 15.) The arrows with bamboo points (Pl. LIX, fig. 14) deviate greatly from the types up to this time described. The delicate long point, 30 to 40 cm., is hollowed out on the inner side only or very little and runs somewhat to a beak-formed point in front and is rounded abruptly at the inner end. The fore shaft, shoved into an excavated socket in the shaft, is tightly wrapped the whole length of its union with Cipo bast. A bird arrow exhibits a short wooden knob, thickened conically toward the front and terminating in a blunt point. (Pl. LIX, fig. 10.) The feathering is arranged upon the same principle as that of the Yuruna, but differs from it in more careful work and in the single points characteristic of the Caraja. The fastening of the feather, moreover, is wrought with black thread (Pl. LIX, fig. 8), or less frequently with winding of Cipo (Pl. LIX, fig. 9), in which often also little tufts of red feathers are caught; also the lower long binding, which here for the most part is effected by windings of thread, and stepped patterns includes often red feathers as decoration. Almost always here also the shaftment is painted with red and yellow varnish in lines, whereby an individual taste is to be recognized in decoration still remaining on several examples.

As already mentioned, the Chavantes and Crahaos, living eastward on the Araguay and Tocantins, are with little deviation to be reckoned in the company of Caraja; only less care is bestowed in the manufacture of their weapons, and so the decoration is frequently omitted.

Whether all the different varieties of points also exist among them is not known. There have been examined arrows with knife-blade points of bamboo (Pl. LIX, fig. 14), those with double-pointed bone tip (Pl. LIX, fig. 6), laid on diagonally at the fore end, arrows with smooth wooden points, and finally those cut from a single piece of Cambayura reed. Still the Chavantes may possess for war also an arrow with toothed points of wood. (Pohl, Reise in Brasilien, vol. ii, p. 30.)

The bows of the Crahaos are somewhat different, since the belly has a flat, guttered excavation, and only one end is cut to a point, while the other end is blunt.

The Aruma arrow, already mentioned, is likewise of Caraja type, but the characteristic toothed point of the Ges stock is here found. (Pl. LVII, fig. 12.)

It remains now only to mention the bows and arrows of the Cayapo, in the Natterer collection, from the region about the sources of the Araguay, in the eastern Matto Grosso. They occupy ethnographically a middle position between the Shingu and East group and the tribes settled on the south of the Mato Grosso. The peculiar bow of the Cayapo (Pl. LIX, fig. 16) is, in spite of its apparent isolated position, to be relegated to the East Brazilian type. Here also the cross section is fixed by the nature of the material. While the remaining part of the bow is nearly straight, its pointed ends, about 10 cm. long, are bent inward at an angle of 120 degrees. In order to give a sufficient excursion to the bowstring of twisted vegetable fiber, a ball of cotton is wound about the bow at the inner part of the nock. The bowstring is knotted on one end and ends with a sling at the other end of the bow. In a wide spiral winding the rest of the string is then carried back, as in the Caraja bow, and caught under compact bands of wrapping about 10 cm. in width. The arrows give evidence in the sewed feathering, as already remarked by Von den Steinen (op. cit., pp. 151, 153) of a long-enduring friendly relation with the tribes of the Shingu, especially the Nahuqua and the Cayapo, which has proceeded as far as the Paranatinga—indeed, perhaps, as far as the Ronuro. Associated with the sewed feathering and the rounder nock, the predominant Ges character of the arrow is also striking. There are found here the Cambayuva shaft made fast to the point by means of a wide wrapping of Cipo; also the long, unilaterally toothed wooden point (Pl. LVII, fig. 12) and the so-called Caraja bamboo point. The winding of the point to the shaft with wrapping of thread is here rude and meager, so that the fore shaft is seen through. (Pl. LIX, fig. 17). A strengthening of the shaft by partial wrapping of the Cipo is seen on the Cayapo arrows and those of the Bororo.

The tribes of the southern Mato Grosso are to be studied in common, although they exhibit great ethnographic differences and, as the chart teaches, are to be ranged partly with the West Peruvian group and partly with the East Brazilian group. They belong to the Paraguay

region and are, since they were compelled to follow an entirely different route of traffic to the southward-flowing rivers, in a directly opposite condition to the tribes of the Madeira, Tapajo, Shingu, and Araguay. Their ethnographic development must stand in direct association with that of southern tribes, shut off from the tribes of the northward-flowing rivers, which, for the most part, are confined within their own drainage regions, and only along subsidiary lines are they in contact with tribes of a neighboring drainage to bring about ethnographic adjustments. However, that the tribes extending farthest north on the Paraguay region came into frequent touch with the tribes neighboring to them is thereby not excluded, and, on the contrary, it is proved, as was shown in the case of the Cabischi arrow and Cayapo weapons. For that reason there can not be drawn up for the ethnographic development of the whole group a balance sheet respecting this region which would be derived through the coming together of many types from different directions into one or through the radiating expansion of a dominating type.

Further, a second motive constrains one to deviate from a hard and fast division, namely, that, as was already seen concerning the Baccairi, a people can develop along entirely diverse ethnographic lines through divisions and wandering away into remote parts. It is the case here with the Bororo, whose western branch approaches the Shingu tribes in their feathering and has received its bow in commerce with the Paraguay tribes, while the eastern branch has held on to the original common mixed type of eastern feathering and bow throughout. These two tribes, whose development is easily demonstrable, can be considered apart when it comes to the study of the fundamental type. On this ground it is well to discuss the Paraguay tribes of the Mato Grosso in common.

The Bororo tribe, the special representative of the native southern Mato Grosso populations, who, if not the autochthones, occupied the region of the southern Mato Grosso as far back as any information of the tribe is had, specially the upper Paraguay portion, existed, indeed, since the previous century in two groups, which have gone forth out of the region previously discussed between the Lorenzo and the Paraguay, and from which outward the eastern section pressed forward into the vicinity of the Cayapo, on the upper Araguay, the western half passing over the Cuyaba and the Paraguay and halting at the western confluence of the Paraguay. The Bororo are a hunter tribe purely, who, being given to fishing and the chase, held on tenaciously to their manner of living and developed an unrestrained free character and a wild temperament, which can not be said concerning close application to the field and the restful activity of the tiller of the soil. While the Government and the missions have succeeded with great difficulty with others, as for the Bororo, with their hostile indisposition to link their interests with those of the colonists and to settle in permanent aldea-

ments, the plan to interest them in the cultivation of the soil did not succeed. They remained hunters as before, and only acknowledged with sufferance a guardianship on the part of the Government while advantages accrued to them in this way. Their support was abundantly cared for, so that they themselves were not brought to want for food or any other necessaries of life. But the hunting and fishing went on in spite of their common occupation. When these no longer served them as a means of livelihood they were pursued as sport. The reduction of the two groups happened at quite different times. While the Bororo of the west were already settled in the first half of the century, the other half extended for a long time hunting and pillaging through the camps before it was possible to bring them to remain for some years on the Lorenzo.

The three collections from the Bororo—that of Natterer in Vienna, that of Rhodes and of Von den Steinen in Berlin—are from the two sections of the Bororo after their separation and, excepting the Bororo of Cabaçal, after their subjugation. There is wanting the type of weapon of the Bororo from the olden time when they were united. Still it is possible to reconstruct the common type, partly, since from both groups pieces of the same type are in hand. Through this it must be accepted that in the Von den Steinen collection of the year 1888, shortly after the settlement of the eastern branch, this type partly returned, and in the Natterer collection of the western Bororo (collected in 1827) it is to be seen that only the eastern Bororo continued the original common type after the separation, and have only through commerce with their neighbors on the Araguay adopted varietal forms. The much longer absence of association of the eastern Bororo in comparison with the western substantiates this view, while much feebler associations with culture and with other tribes would render possible and easy a constancy in the making of weapons which are perfectly sacred to them as their crowning peculiarity. Let us examine, therefore, first, most carefully, the bows and arrows that Von den Steinen collected in the year 1888 in the colony of Thereza Christiana (Pl. LX, figs. 1 to 9), newly established in 1887, from the point of view that we have here to do with a purely hunter folk whose peculiarities culture could not have wiped out.

The bow was their most precious possession as the only means of livelihood. This belief finds its expression in the estimation in which it was held. Von den Steinen says (op. cit., p. 502) that after the bow and arrow of a head of a family are burnt up in the funeral fire along with the household stuff, the survivors receive from friends bows and arrows as pledges for the foundation of a new household. Arrows, moreover, furnish the present of the lover to the girls and women of the ranchao, by whom they are given over to their brothers. With arrows and especially shaped bows the fortunate slayer of a jaguar would be distinguished, and arrows furnish the medium of exchange for cotton

and tobacco. In their ceremonies these weapons play a leading rôle. In the consecration of the skull of a dead man, a long and complicated mortuary ceremony, five bows set up in a semicircle form the foundation of a kind of sanctuary. Whether in the traditions here as on the Shingu the arrow plays a special role is not known. The great value of the bow and arrow naturally finds expression in the carefulness of their manufacture. Since they set forth the characteristic attribute of the hunter they are prepared only by the men, who expend a painstaking accuracy and care upon their production. Perhaps centuries of using the bow and arrow have developed different kinds for different functions, which show, indeed, the same characteristic marks of the tribe, differing in the choice of material and the form of the point, The arrows for war and for hunting larger mammals, as the jaguar. being much heavier in consequence of the use of the dense Seriba palm wood for the shaft, have their penetrating power greatly increased. Arrows with shaft from light Cambayuva reed are lighter and have longer flight.

These original, characteristic types of weapons, since they seem to remain relatively pure, enable the student to recognize through them tribes far away and correspondences with neighboring forms. From their next neighbors, the Cayapo, their hereditary enemies, they appear never to have learned the great strengthening of the shaft by wrapping it with Cipo bast, and this makes obtrusive the similarity of their arrow with that of the Caraja and with certain forms on the Shingu. Firstly, in the feathering, beautifully executed and decorated with little tufts of feathers, a relationship with the Caraja arrow can not be recognized, likewise the form of the bamboo point of the peccary arrow is the same as that of the Caraja bamboo point previously described. To both tribes, furthermore, the plain arrow cut out of a single piece of Cambayuva reed is common. (Pl. LIX, fig. 15). The barbed wooden point of the fishing arrow is suggestive of the Ges form.

All these correspondences point to the east or the northeast; for all that, relationships with the western tribes are not to be denied. The points made from the tubular part of the humerus bone of a monkey (Pl. LVII, fig. 8) are common to them and the tribes on the Shingu, the west Bororo, and the Guato. An artificial winding of the dark Cipo, associated with the loosened wind of the reed at the butt end of the feathering, points to similar work on the northern Paraguay, the black and white wrapping of thread for the fastening of the feather (Pl. LX, fig. 9; cf. fig. 14) is likewise in use among the southeastern tribes—the Guato, for example. The attachment of the bow to the Peruvian type is recognized by the natural peculiarities of the materials and the cross section (Pl. LX, figs. 1 to 7), as must strikingly appear, since these examples stand out isolated in the eastern Brazilian bow region. The black palm-wood bows with greatly thickened ends are somewhat aberrant by reason of their long elliptical, somewhat hollowed cross section.

The fastening of leaf filaments on a bow as a premium for having slain a jaguar as well also as the beautiful decorations on the chief's bow with wrappings and tufts of feathers are entirely like the Caraja custom.

While the Bororo, just described, appear to have preserved the type of their hunting weapons relatively pure up to the time named, the weapons of the Bororo of Cabaçal and those of Campanha, the western groups on the Cabaçal and the Jaura seem to have yielded more to foreign influence through contact with other tribes. These Bororo also, already having become sedentary, in the first half of the century held fast to the old custom, were prejudiced against agriculture and continued hunters. However, through continuous touch with culture and with their influence destroyed they are to-day entirely subdued. The dispersion of weapons went hand in hand with the wanderings of this tribe. The two collections from these Bororo were brought together at different dates. That of Natterer, assembled in 1827, containing arrows of the Bororo of Cabaçal and Campanha, comes from a time in which the Bororo of Cabaçal were still ranging free in the wilderness, but the Bororo of Campanha had then been brought under control for some years. It is now seen that the arrows of the Bororo of Cabaçal have from the first held to the original type to which the Bororo on the Lorenzo return. The broad bamboo point of the characteristic jaguar arrow (Pl. LX, fig. 8), which is so cut that the knot on the reed shaft runs across the point, the loose shafting of the point as well as the working of the intractable Seriba palm wood to a very long foreshaft, associated with a very short Cambayuva reed shaft is a reminiscence of the old union with the eastern Bororo. The feathering, however, with the feathers toothed on the margin has decidedly the characteristic of the Guato arrow (Pl. LX, fig. 14), though in this tribe there is wanting the peculiar arrangement of the nock. Whether this influence can have been exerted upon their westward wandering when they may have come in contact slightly with the Guato, or happened for the first time later after they already had settled on the Rio Cabaçal, is in doubt. An association with the Guato, the water nomads of the upper Paraguay, is very probable. The bow manifests no variations whatever. It is about the same simple unadorned weapon of the original Bororo on the Lorenzo. That these Bororo did not know the decoration of the weapon with little feather tufts, shows that the Bororo of the East had not been brought in contact with this technique originally but, as already mentioned, have taken it from their later neighbors.

The Bororo arrows of the Campanha in the Natterer collection, which were received from them after they had already become settled by conquest, show an advance in the migrations hinted at. Before all else, the Cambayuva reed used for shafts of arrows was entirely replaced by the Uba reed. The abundance of the Uba reed (*Synerium saccharoides*), on the one hand, and the influence of the Guato using it and perhaps of the Baccairi, on the other hand, have occasioned this

change. As a single survival of the time before the separation of the Bororo, there is to be seen among the Bororo of the Campanha the jaguar (Pl. LX, fig. 8) arrow point, with foreshaft of Seriba palm wood. The feathering of this arrow is here entirely different. (Pl. LX, fig. 17.) The feathers are, in spite of the constant disasters of this tribe, set on the shaft with very much more elegance and care. When the Baccairi of the Tapajoz region are contrasted with one another, this technique would seem to have come only from the Baccairi on the Paranatinga, earlier united with the Bororo, while the wide separation of the Bororo from the Baccairi of the Shingu does not allow contact with them to be thought of. Moreover, the highly developed technique hints that the reception of the sewed feathering must have occurred already in much earlier time—indeed, shortly after their wandering into this region. Eventually this form, indeed, had already become known to the Bororo before the split and was lost by the eastern Bororo. The Pareci, the northwestern neighbors of the western Bororo, can not be regarded as intermediaries, because they, in more recent times, as was seen, first received the sewed feathering from the north. As for the origin of the Bororo, sewed feathering on the Shingu calls to mind that also on that river the bone point from the humerus of the monkey (Pl. LVII, fig. 8), as well as the wooden point of the Baccairi and the Nahuqua with side barbs of palm splint wrapped on, were known to the Bororo (Pl. LVII, fig. 14). In opposition to this approach to the Shingu type is the setting aside of the old Bororo bow and the adoption of the Guato bow (Pl. LX, fig. 10), only a little modified. An unpracticed eye would with difficulty discriminate the bows of these two tribes. These bows belong to the eastern Brazilian type, and, indeed, also here is to be found the bow with bast wrapping diffused in the western part of this region. The more or less round, slightly bent bow stave, made from the brown wood of the Caranda palm, is throughout its entire length closely wrapped in imbrications, with about 2 cm. broad strips of Cipo negro or Liana bast, only the ends are free and bluntly pointed. A strong palm fiber bowstring is carried back on this wrapping for a quarter of the length of the bow, as in those on the Shingu and the Cajara.

The second collection of the western Bororo, by Rhode, in 1884, brings to us another stadium of development. In the sixty years that passed after Natterer's journey, the disadvantageous influences of culture likewise worked to the detriment of the Bororo of Campanha and of Cabaçal, and from Von den Steinen's account (op. cit., p. 442) they to-day form only a poor, starving society. This is more wonderful, because after the year 1827 a certain constancy in the making of their weapons is shown. The sewed feathering, no less than the bone points, has become entirely domesticated. A similar bamboo point (Pl. LX, fig. 16) to that found among the Baccairi and Yuruna occurs also here and is associated with the sewed feathering. It appears also

to have come among the Bororo from the Baccairi. However, as already made clear, it is not easy to say whence the Baccairi received the point. But therewith also has the contact with the Baccairi belonged, since after the settlement of the Bororo the conflict northward must have ceased. It has at the present time a stronger assimilation with the Guato, the water nomads, which went on until the Bororo came hereabout. So, as at this place the Bororo received the bow from the Guato in this region, these last, in reciprocity, took the bone point. The Uba reed has entirely superseded the Cambayuva reed. To the stout, long shaft, which often, as among the Guato, is made up of several pieces bound together with wrapping of Cipo, is made fast a harder knotty wooden foreshaft by means of Cipo wrapping. These are all the arrows with which the Guato are familiar. Out of the originally much-diversified arrow forms remain now only two, the one with the bamboo point and the one with the bone point. With the bamboo point (Pl. LX, fig. 16) is associated the sewed feathering; with the bone point (cf. Pl. LVII, fig. 8) belong a feathering similar to that of the Guato type. However, the peculiar form of the barb is always wanting.

Of the tribes that live south of the Bororo no one is appropriately to be assigned to the Mato Grosso. They dwell together in the deep swampy lowlands of the Paraguay, which furnish the transition to the great Plains of the Gran Chaco. However, there are some tribes yet to be brought into this discussion, since the ethnographic connection with the Bororo are so striking that omitting them would leave the ethnographic picture of the Mato Grosso incomplete.

The Guato, already frequently mentioned, a people in their tribal affiliations quite as unknown as the Bororo, lived, so far back as information of them goes, upon the upper Paraguay and its tributaries, which, at the time of the inundations during half of the year, when their homes are partly submerged, they navigate as genuine water nomads in their canoes. Driven to the water, they live chiefly upon fish, which, in the absence of hooks, they hunt skillfully with bow and arrow (Castelnau, Voyage, etc., III, p. 9), an art which is commonly spread over South America.

The bow (Pl. LX, fig. 10–13), as mentioned, almost the same as that of the western Bororo, has as a variation a thick tuft 5 cm. long, which is shredded from the end of the Cipo filaments and wound fast about the bow, serving for a better security of the bowstring. The Cipo winding is cleaner and less carefully laid on than among the Bororo. The bowstring is made from the shredded fiber of the Tucum palm, or, according to Castlenau, also out of the gut of the monkey (Castlenau, Voyage, III, p. 14), and is, as among the Bororo, in its prolongation wrapped less close and fast about the bow. The arrows of the Guato are distinguished by the feathering, the same as those of the Bororo. Along with the bone point, which was, indeed, transferred from the

Bororo, and also with a harpoon arrow with unilaterally barbed point, there is in the Rhode collection a bamboo point (Pl. LX, fig. 15) having nothing in common with those of the Bororo. It is narrow, is a flattened circle in cross section, and is made fast upon the short foreshaft by means of a narrow band of Cipo wrapping merely, and the foreshaft is not, as generally, inserted into the point, but is spliced on. The Natterer collection furnishes the same style of arrow, but only with bone point. Arrow shafts made from pieces joined, already mentioned among the eastern Bororo, are held together among the Guato with fish glue. (Castelnau, op. cit., III, p. 14.)

The feathering (Plate LX, fig. 14) of the Guato arrow is worthy of remark in its deviations from that of the Bororo. Generally one-half of the plume of the feather is cut toothed, as also partly among the Bororo of Cabaçal. The fastening of the smooth feather lying flat on the shaft is effected in the customary technique of the eastern Brazilian type by means of a cotton thread at the inner and outer end, which is blackened at the upper extremity. Sometimes Cipo is also utilized, which mostly continues from the upper wrapping to the lower in a longer spiral, simply encircling the shaft. This also calls to mind similar ones occurring among the eastern Bororo. The notch is worthy of notice. Two pegs of hard palm wood driven into the border of the nock prevent the reed from being split and rendered useless by the discharging of the arrow. This practice was found already in the Mauhe feathering (Pl. LIX, fig. 13), wherein a notched wooden nock is driven into the end of the arrow, a technique distributed throughout the entire northeastern region of South America and having its origin in Guiana. A more extended account will be given in the projected work. The technique employed by the Guato in the manufacturing of the notch differing from the customary method allows the belief that they discovered it independently of the northern nock technique. Outside of a few tribes neighboring to the Guato the nock pegs are nowhere found.

From the Guana, the last people here to be considered, there is in the Natterer collection only one long harpoon arrow with the label "Guana, Presidio Albuquerque and Miranda on both banks of the Paraguay, Mato-Grosso and Bolivia." It is absolutely of the Guato type. The shaft is of Uba reed; the foreshaft is fastened on by means of Cipo, and the long feather or shaftment terminates in nock pegs, only there is upon the smooth foreshaft of redwood, most commonly used in the Gran Chaco, an iron point set with bark pointing backward. Through this similarity with the Guato and indirectly with the Bororo arrow the story (von den Steinen, op. cit., p. 379) of the coming of the Guana from the north out of the Arinos region gains probability. Dobrizhoffer, who traveled from the Chaco westward from Albuquerque, alleged that they differed from the Chaco people and that they did not use the horse. Natterer and Castelnau found them in the Presidio Albuquerque and Miranda, in three hordes, the Guana proper, the Terenos, and the Laianos. While also the use of the horse is not mentioned among the

Guana proper, the Laianos and Terenos are described as riding people (Castelnau, op. cit., II, p. 469), who carry the customary weapon of the Chaco Indians, lances with iron points, clubs, bows with small arrows, and wearing the bodoque or labret received from the Guarani of Paraguay. To this assertion correspond some bows and arrows of the Terenos in the Berlin Museum, which completely correspond to the Chaco type. Although the three mentioned tribes are not to be regarded linguistically as Nu-Aruak the different modes of living and different character of weapons show an already very early separation.

The Terenos and the Laianos quite early, perhaps shortly after the Chaco people had begun to ride the horses introduced by the Spaniards, were driven from the common possession on the upper Arinos toward the northern Chaco. which had been seized, where they, as well as the Guana, were called a horseless nation by Dobrizhoffer. The Guaycuru, Mbaya, their neighbors, gained through the ownership of horses a great advantage over them and brought them under their sway. (Dobrizhoffer, Geschichte der Abipones, I, p. 161.) As will be frequently seen in a subdued people, the Guana accepted entirely the mode of life of their conquerors, and also their weapons, which they later continued using after they had again gained their freedom. Perhaps, at first, long after the wandering about had been taking place with these Guana, the remaining Guana also drew off to the southward. A village of the Guana near Cuyaba, 1848, was still called in that language Akten. (Von den Steinen, op. cit., p. 550.) They settled in the vicinity of the Guato on the Paraguay, whereby an ethnographic commerce was effected.

Southward of the Guana the tribes living on the banks of the Paraguay are genuine Gran Chaco stock, whose history so far as known has been closely knit with that of this region. It might be here remarked that the form of arrow known from the descriptions of the Bororo, Guato, and Guana, finds many transitions to the type common in Paraguay, while the transition to the Chaco form takes place first indirectly through the Paraguay type. Furthermore, in the same way, these tribes are related to one another through their bow types.

The bow wrapped throughout with Cipo (Pl. LX, fig. 10) is to be seen in several differentiated forms as far as southeastern Brazil. The distribution of the nock pegs (Pl. LX, fig. 14) is evidenced by single unlabeled old arrows of pure Chaco type which are in the museum at Edinburgh. Whether these received the pegs in contact with the Guato type, or whether the origin of this technique is to be sought in some portions of the Chaco region, from which it was communicated to the Guato, is not disclosed. The practical value of this applied nock is easily seen. A technique of this kind can, therefore, since it does not differ outwardly from the character of the type, easily have been borrowed from a tribe extremely conservative in the giving out of their weapons, as we are able to demonstrate among the Chaco people, whose

smaller bow of Curepay wood has been found in prehistoric graves in Jujuy, in the western Chaco region.

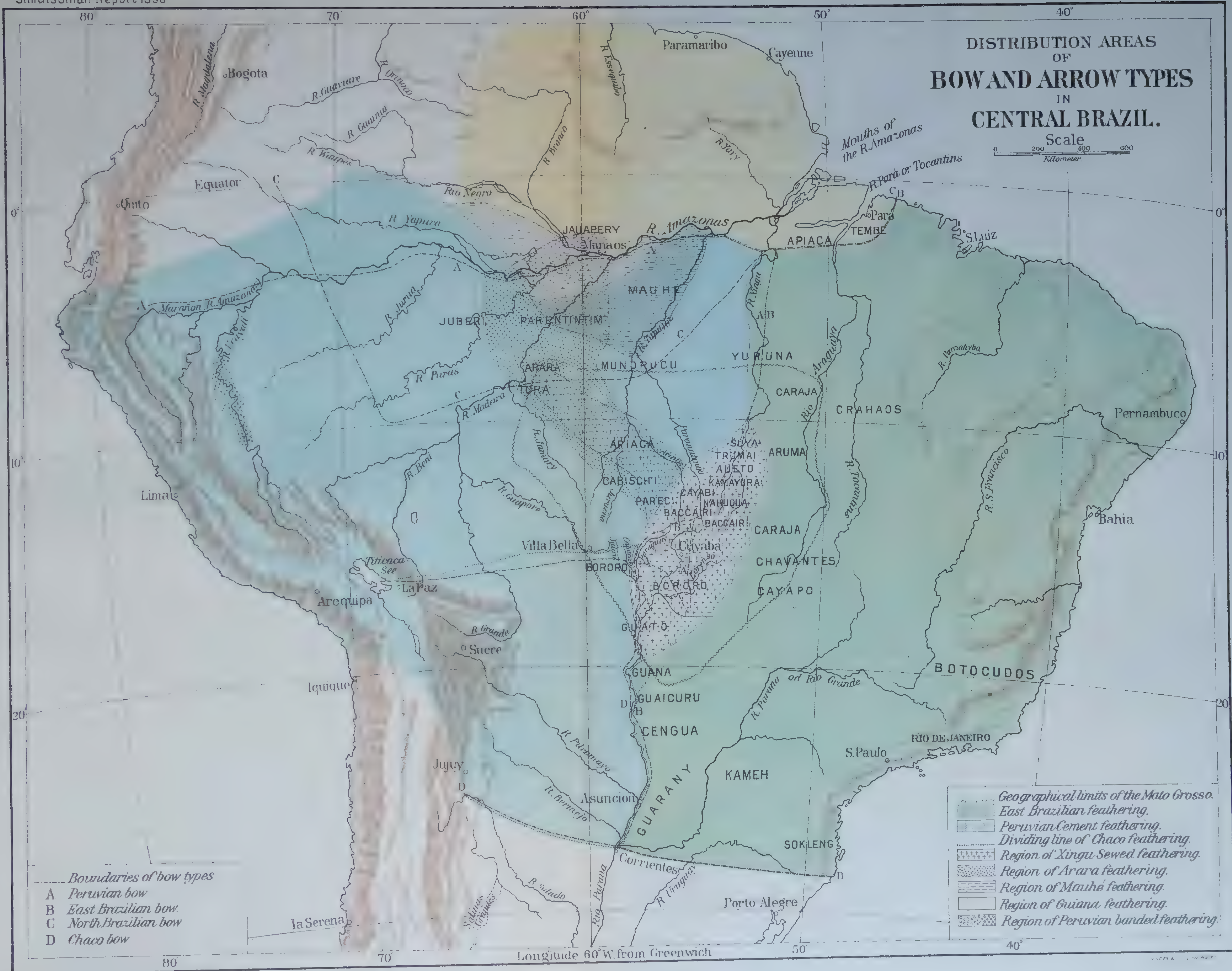
We may now bring together the results reached for the southern Mato Grosso. It is known that, with exception of small movements in opposite direction between neighboring peoples, an ethnographic stream, rich in its influences, has flowed from the south, passing out from Paraguay and reaching to the Bororo. As well the Paraguay feathering, as the winding of the bow with Cipo may be traced as far as the Bororo. Afterwards this stream is met by one opposing it from the north. It is indeed astonishing, but its influence does not pass the Guato. The sewed feathering is confined to the Bororo; only the bone point is now to be found among the Guato. The spread of the Uba reed, as mentioned, founded on its abundant supply, can not testify directly of an ethnographic relationship.

The ethnographic picture of the whole Mato-Grosso appears, in spite of its original complexity, to be strikingly unified on closer inspection.

We see in the northern region two great ethnographic streams, one from the west and one from the east, running toward and in the Shingu encountering each other, so as to result in a mixed type. Between them is thrust in a third type, which perhaps, on the upper Shingu, at least so far as the feathering goes, has its center of dispersion toward the Tapajoz and Tocantins. A small by-stream is to be traced from the northwest to the Arara, the Juberi tribes, for example, and to the southeast on the Tapajoz from the Mauhe. In the southern Mato-Grosso runs a main stream along the Paraguay. A second one is directed southward from the Shingu region. Further influence of groups lying farther off is not to be recognized in the Mato Grosso.

The ethnographic character of a people is generally not conterminous with its linguistic affiliations, but depends also on a place which a people occupies with reference to its neighbors, and on possibilities of an ethnographic adjustment conditioned thereby. Original peculiarities of groups of tribes, like the Tupi, are to be occasionally found, but these have through many adjustments with others, not belonging to the stock, lost characteristics or have been changed therein. Whether the widely diffused stepped decoration (Pl. LVII, fig. 5), found all over northern South America, as well as the quill ring (Pl. LVIII, fig. 17), are to be regarded as tribal characteristics is to be decided by further and more careful observations.

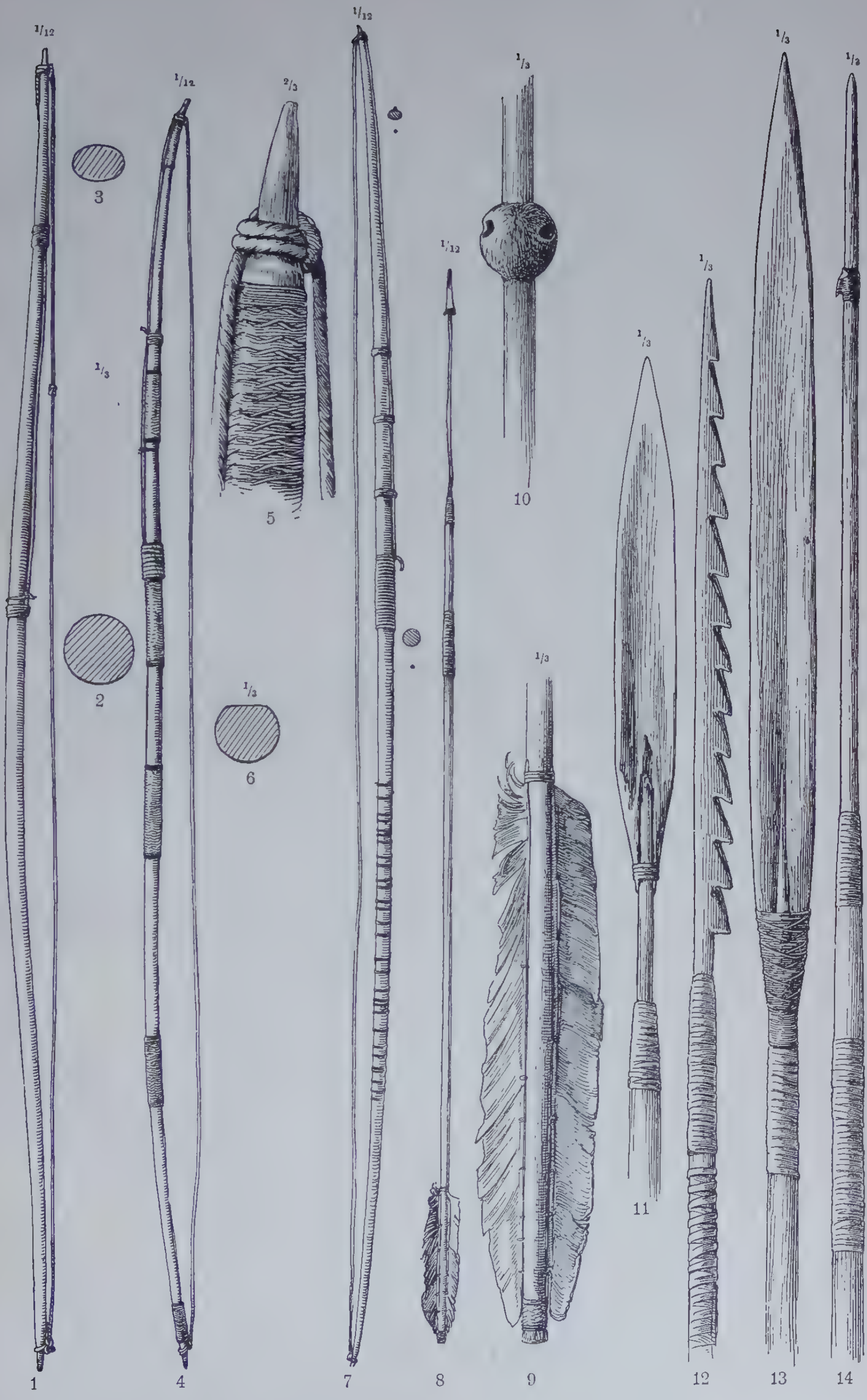
The question how far the conclusions reached concerning the development of the Mato Grosso furnish generalized results for other regions, and how far other momenta for the completion of the ethnographic picture are to be considered, will be attempted in a later work.


DISTRIBUTION AREAS OF BOW AND ARROW TYPES IN CENTRAL BRAZIL.
Scale
Kilometer.
Boundaries of bow types
A Peruvian bow
B East Brazilian bow
C North Brazilian bow
D Chaco bow
Geographical limits of the Mato Grosso.
East Brazilian feathering.
Peruvian Cement feathering.
Dividing line of Chaco feathering.
Region of Xingu Sewed feathering.
Region of Arara feathering.
Region of Mauhé feathering.
Region of Guiana feathering.
Region of Peruvian banded feathering.
Longitude 60° W. from Greenwich
Bogota
Paramaribo
Cayenne
Quito
Equator
Manaos
JAUAPERY
R. Amazonas
Mouths of the R. Amazonas
R. Pará or Tocantins
Pará
S. Luiz
APIACA
TEMBE
MAUHE
JUBERI
PARENTINTIM
MUNDRUCU
YURUNA
ARARA
TORA
CARAJA
CRAHAOS
Pernambuco
ARIACA
SUYA
TRUMAI
AUETO
KAMAYURA
ARUMA
CABISCHI
CAYABI
PARECI
NAHUQUA
BACCAIRI
CARAJA
Bahia
Lima
Villa Bella
Cuyaba
BORORO
CHAVANTES
CAYAPO
Titicaca See
La Paz
Arequipa
GUATO
Sucre
GUANA
BOTOCUDOS
Iquique
GUAICURU
CENGUA
RIO DE JANEIRO
S. Paulo
Jujuy
KAMEH
GUARANY
Asuncion
SOKLENG
Corrientes
Porto Alegre
La Serena
R. Negro
R. Yapura
R. Madeira
R. Purus
R. Jurua
R. Ucayali
R. Beni
R. Guapore
R. Tapajos
R. Xingu
R. Araguaya
R. Tocantins
R. Parnahyba
R. S. Francisco
R. Parana od Rio Grande
R. Pilcomayo
R. Bermejo
R. Salado
R. Uruguay
Rio Parana
R. Branco
R. Essequibo
R. Yary
R. Orinoco
R. Guaviare
R. Guainia
R. Waupes
R. Magdalena
Marañon R. Amazonas
R. Grande
80°
70°
60°
50°
40°
0°
10°
20°

EXPLANATION OF PLATE LVII.

[Figs. 1 to 14, Berlin Museum.]

1. Double-curved bow of the Aueto, Upper Shingu.
2. Cross section of the same at the grip.
3. Cross section of the same at the ends.
4. Double-curved bow.
5. End of the same showing stepped pattern of wrapping.
6. Cross section of the same at the middle.
7. Single-curved bow, with rawhide rings stretched on, Baccairi tribe.
8. Arrow with Shingu sewed feathering and point from monkey humerus set on, Aueto.
9. Shingu sewed feathering, Aueto.
10. Tucum nut whistle on shaft, Suya.
11. Bamboo point, Kamayura.
12. Bamboo wooden point, Ges from Kamayura.
13. Bamboo point, Baccairi.
14. Wooden point, with barb of ant bear zygomatic process.

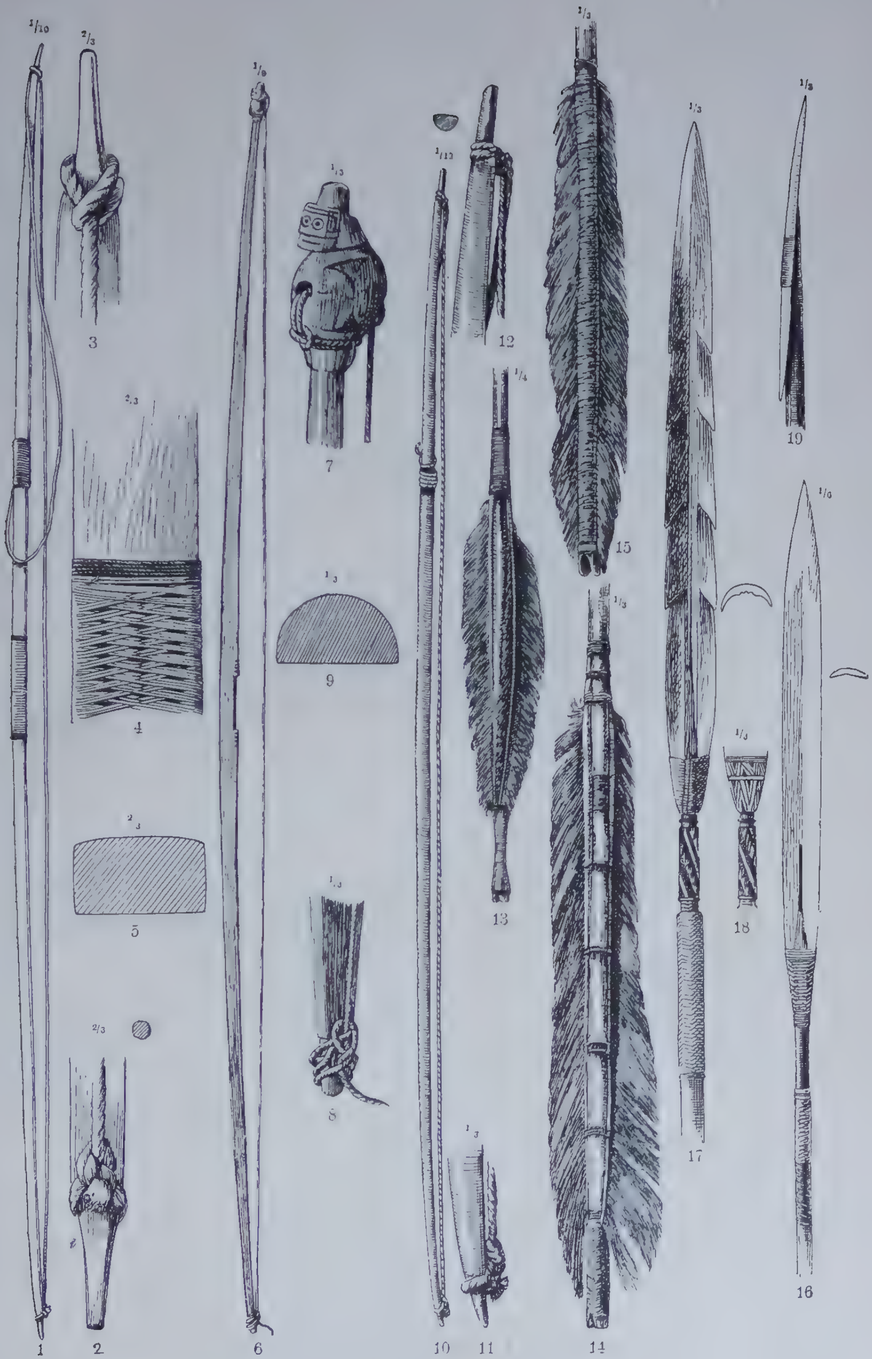


BOWS AND ARROWS OF CENTRAL BRAZIL.

EXPLANATION OF PLATE LVIII.

[Figs. 1 to 5, 10 to 15, Berlin Museum; 6 to 9, Copenhagen Museum; 16 to 19, Stockholm.]

1. Bow, Peruvian type, Yuruna tribe.
2, 3. Ends of the same.
4. Middle part wrapped with thread.
5. Cross section in the middle.
6. Bow with carved end, Mundrucu.
7, 8. Ends of the same.
9. Cross section of the same.
10. Bow, North Brazilian type, Mauhe.
11, 12. Ends of the same.
13. Mauhe feathering, Mauhe.
14. Arara feathering, with stepped pattern and quill ring on the nock.
15. Peruvian cemented feathering, Baccairi.
16. Tapajos bamboo point, with stepped pattern in wrapping. Apiaka.
17. Toothed bamboo point, with ornamentation in quill work and stepped weaving, Arara.
18. Quill work and colored patterns effected in the wrapping of threads.
19. Bone point set on diagonally.

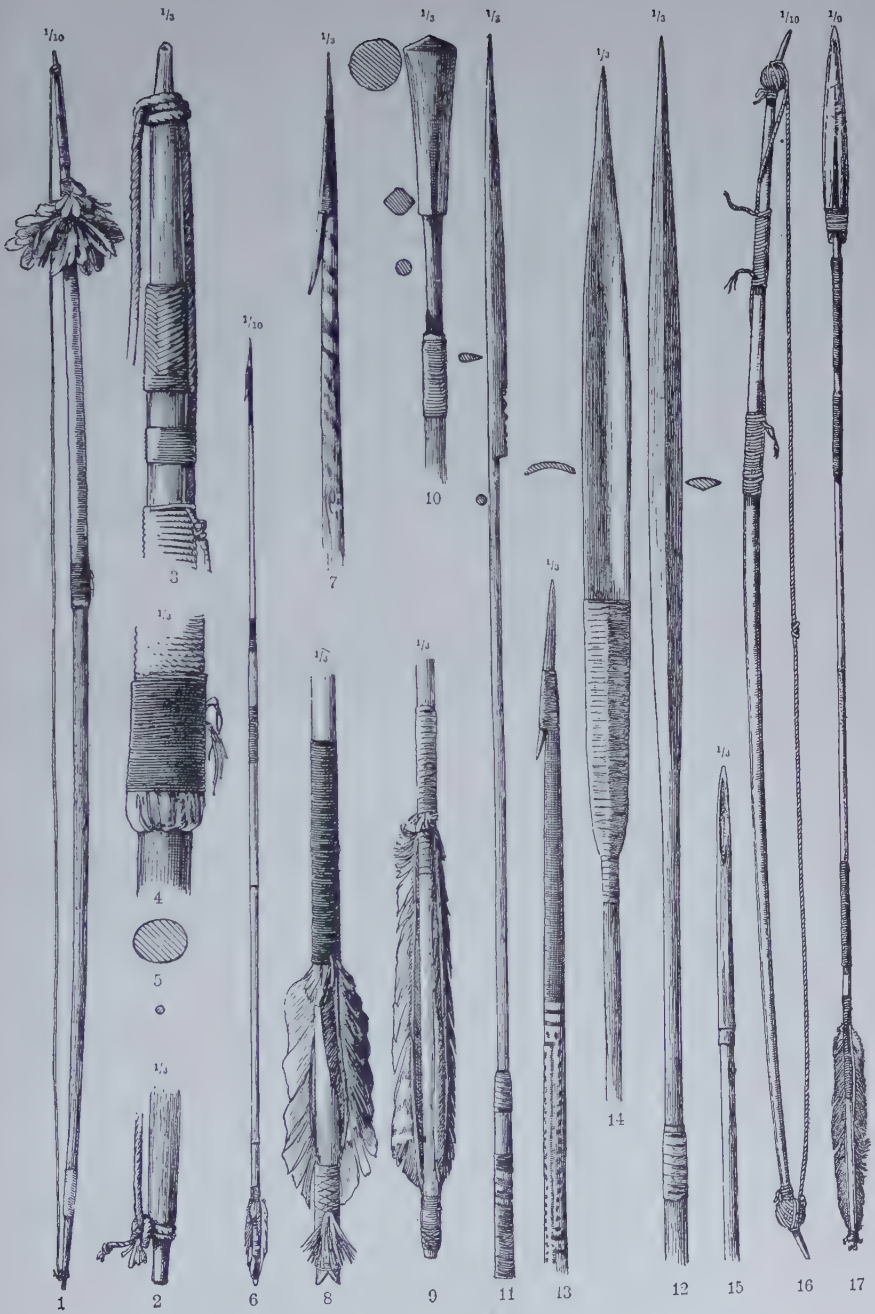


BOWS AND ARROWS OF CENTRAL BRAZIL.

EXPLANATION OF PLATE LIX.

[Figs. 1 to 5, Berlin Museum; 16, 17, Vienna Museum.]

1. Bow, East Brazilian type, Caraja.
2, 3. Ends of the same.
4. Middle or grip, with packing or wrapping of leaf.
5. Cross section.
6. Arrow with bone point cemented on diagonally.
7. Point of the same.
8. Feathering, wrapping of black thread, east Brazilian type.
9. Feathering, with wrapping of Cipo, east Brazilian type.
10. Wooden point of a bird arrow.
11. Wooden point of arrow, single edge, Caraja.
12. Wooden point of arrow, two-edged, Caraja.
13. Point of fish spine set diagonally on a painted foreshaft, Caraja.
14. Bamboo point, Caraja.
15. Point of an arrow out of a single piece of Cambayura reed, Caraja.
16. Bow, with cotton wrapping, Cayapo.
17. Arrow, with bamboo point, Cayapo.

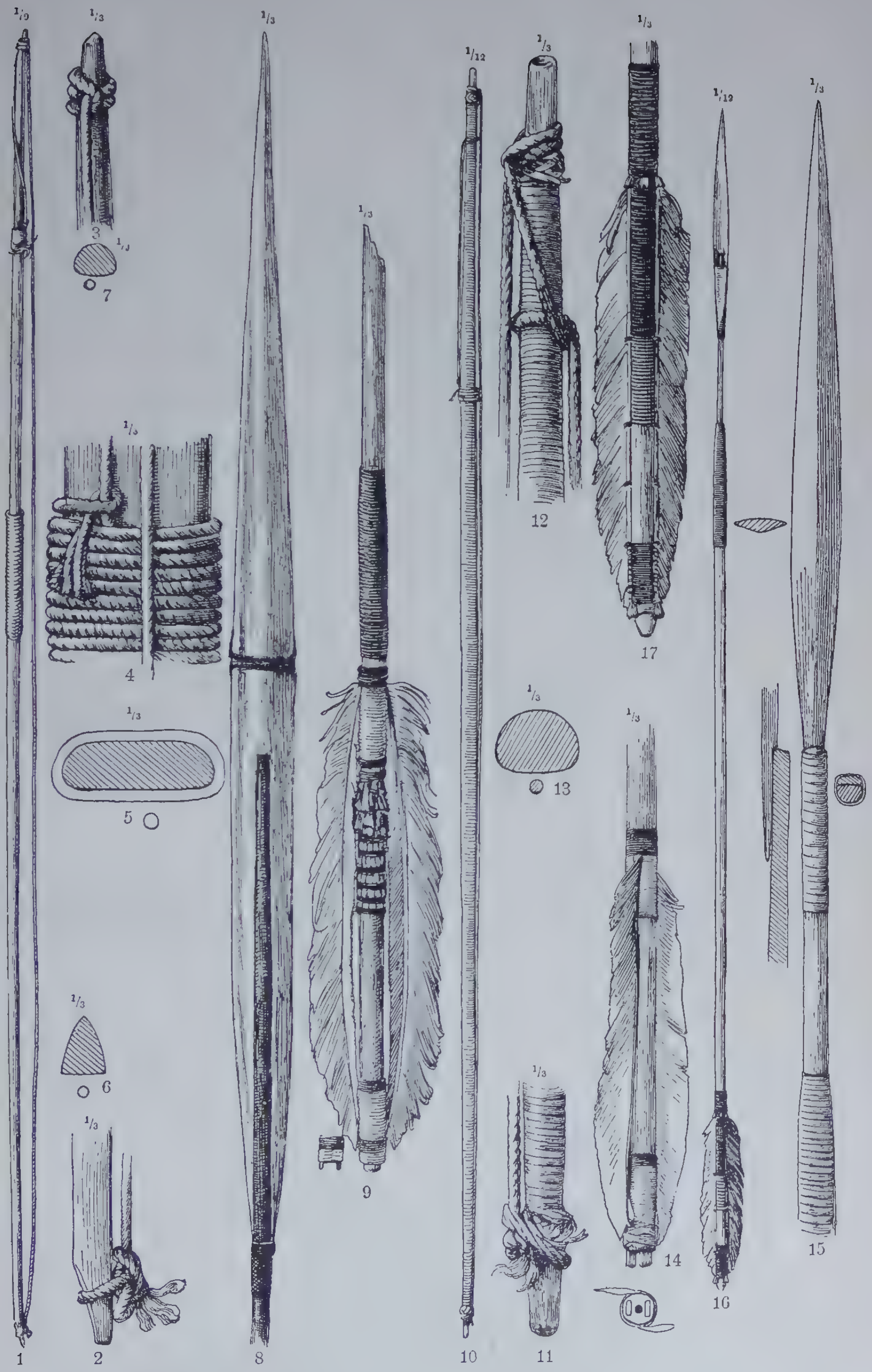


BOWS AND ARROWS OF CENTRAL BRAZIL.

EXPLANATION OF PLATE LX.

[Figs. 1 to 17, Berlin Museum.]

1. Hunting bow, Peruvian type, eastern Bororo tribe, Rio Lorenzo.
2, 3. Ends of the same.
4. Middle part or grip.
5, 6, 7. Cross sections.
8. Bamboo point of jaguar arrow, eastern Bororo, Rio Lorenzo.
9. Feathering of the same, eastern Brazilian type.
10. Bow, with Cipo wrapping and grommets, Guato.
11, 12. Ends of the same.
13. Cross section of the same.
14. Feathering, with nock pegs set in.
15. Bamboo point.
16. Arrow, with bamboo point, west Bororo.
17. Sewed feathering of the Bororo, western Bororo.



BOWS AND ARROWS OF CENTRAL BRAZIL.

ACCOUNT OF THE WORK OF THE SERVICE OF ANTIQUITIES OF EGYPT AND OF THE EGYPTIAN INSTITUTE DURING THE YEARS 1892, 1893, AND 1894.[1]

By J. DE MORGAN.

On the 1st of September it was two years since, charged by the Government of His Highness the Khedive, with the administration of the antiquities of Egypt, I definitely assumed full control of an office which I had held pro tempore for about six months, and which, in spite of the experience already gained, seemed to me none the less a very heavy burden.

It is not enough, as you know, that a person be merely a good administrator in order to properly direct this great service; one must be an Egyptologist as well, and while my good intentions might contribute to the conduct of affairs, it could not be so with regard to Egyptology. I found that to succeed Mariette and our colleague, Maspero, was an honor difficult to support.

My studies had always turned to Asia. I was not an Egyptologist. Consequently only my administration and my discoveries can excuse my ignorance of the hieroglyphs. I hoped, however, that linguists would be satisfied if I furnished them with their documents, while I devoted myself entirely to my researches.

In order to show you plainly the work done by the Service of Antiquities since my arrival in Egypt, it is indispensable that I divide my subject, because very often enterprises of quite different nature have been executed at the same time, and it would be impossible to enumerate them in chronological order.

I shall speak first concerning excavations, then about the conservation of monuments, then about the museums, and finally about the publications of the Service of Antiquities in Egypt.

[1]Translated from Actes du Dixième Congrès International des Orientalistes, session de Genève, 1894. Leide, 1897. Section iv, Égype et Langues Africaines, pp. 3-33.

EXCAVATIONS.

I shall bring to your attention the various places in which excavations have been effected within the last two years, following the geographical order, for any other arrangement would be impracticable, since various works were carried on simultaneously. I shall commence with the north of Egypt, and proceed toward the frontiers of Nubia, ascending the river.

Sa-el-Hagar (September, 1893).—These diggings, at the place where the great discoveries of bronze had been made, have furnished a goodly number of statuettes, some of them of great rarity, among which I may mention a statuette of Pacht, representing a cat sitting on the shoulders of a man.

Abou-Roach (June 15–October 1, 1893).—The work here revealed a vast subterranean structure whose use is as yet unknown, in which were found in the sand a great many statuettes of bronze and enamel, several of them remarkably delicate. These objects represent the rats of Pharoah, animals sacred to the god Nefer-Toum.

There formerly existed on the plateau of Abou-Roach a number of tombs and some pyramids. These monuments are now destroyed, and up to the present time no other research has been attempted in these regions.

Gizeh (August, 1892).—During the period of organization of the Museum of Gizeh I made some excavations in the neighborhood of the great pyramids. One of these brought to light a limestone sarcophagus of a certain Uta, priest of the pyramid of Mycerinus about the end of the fourth dynasty. New excavations (March–April, 1894) led to the discovery of a large pit, the examination of which is not yet concluded.

Abou-Sir (August–October 1, 1893).—To verify the assertions of Perring concerning the pyramids of this place, I had the most considerable of the three monuments opened. There I found, as the English explorer had asserted, the ruined chambers. At the spot indicated on the chart of Lepsius, under the head of Pyramid No. XVII, diggings carried on by my orders brought up, not the discovery of foundations of a pyramid, but the remains of a vast mastaba, constructed for a certain Ptah-Chepses, a high functionary of King Sahoura of the fifth dynasty. This monument, very remarkable for the engraving as well as for the delicacy of its bas-reliefs, was composed of numerous halls, only two of which are in a good state of preservation. A spacious court, ornamented with a colonnade, extended south of the principal building. One of the rooms was supported by two lotus-shaped columns, of the purest style, whose capitals, forming a bouquet of the lotus, are the most ancient known. Five giant statues ornamented the rooms of this mastaba. The place they occupied against the walls or in the naos is readily discernible; their transport is figured on bas-reliefs on the exterior walls. Finally a graffito traced in hieratic

on one of the walls informs us that the neighboring statue was erected for King Sahoura himself.

Mit-Rahineh (August, 1892).—The excavations undertaken on the site of the temple of Ptah brought to light two statues of this god, 4 meters high and made of hard sandstone. These two colossi are the largest divine statues thus far discovered. The sanctuary also contained a boat in rose-colored granite and another in solid limestone, surmounting a naos, containing a statue of the god Khnoum, a bust in limestone representing a king, perhaps Rameses II, and finally a group in rose-colored granite of the god Ra-Hor Khouti and of the Pharoah Rameses II.

(August, 1893.)—Excavations of little importance made in the koms led to the discovery of the remains of the studio of a sculptor of the Ptolemaic epoch. The models in limestone and plaster, the molds and the casts furnished at once specimens of the two schools, which had flourished in the valley of the Nile, that of the Egyptian and that of Greek art.

Saqqarah (January, 1893).—While I supervised in person the work in the Saïd, E. Brugsch-Bey, conservator of the Service of Antiquities, carried on some excavations on the site of the necropolis of Saqqarah, concerning which he had been for a long time in doubt. These researches were crowned with complete success; for in a mastaba of crude bricks of the fifth dynasty, the chief of the works found two painted limestone statues of perfect execution. One represented a sitting person, the other a scribe, unfortunately unknown, crouching in the attitude of a man waiting for orders. This statue is one of the most admirable achievements of ancient art; only the "Sheik-el-Beled" and the "Scribe" at the Louvre can be compared with it. These two statues were inclosed in hollow niches in the crude brick walls of the steps of the mastaba.

(July, 1893.)—I had devoted the entire summer of 1893 to the study of the necropolis of Saqqarah. The considerable excavations formerly executed by Mariette guided me not only for my investigations in that locality, but also for those which I proposed to make in the other necropolises of the ancient and middle empire.

The soil of Saqqarah has been many times removed for examination of the tombs. Already, at the time of Pietro della Valle's travels in Egypt, the fellahin knew all the secrets of the discovery of mummies. But it was especially after the great work of Mariette that this part of the desert became a veritable chaos, where heaps of ruins and cavities resulting from excavations followed each other like the billows of the sea.

I had just arrived in Egypt, and of course was not yet accustomed to researches in a sandy soil. I therefore resolved to profit from the diggings of Mariette and only to attack those sites left untouched by my illustrious predecessor.

Following the avenue of the Sphinx, the discoverer of the Serapeum had contented himself with examining the level of the pavement and had not pushed his diggings deeper. It was evident, however, that the entire space under the avenue itself had not been visited since the time of the building of the avenue of the Serapeum. By observing the line of that road you notice that it passes about 40 meters north of the pyramid of Teti and along the north façade. It is, however, known that the royal tombs have always been surrounded by tombs of high functionaries. It was therefore most likely that the avenue contained the remains of funeral monuments of high personages of the epoch of Teti.

Inspired by these deductions, some days after our installation in Mariette's house I began work to the northwest of the pyramid of Teti. The avenue of the Sphinx was easily found again, and some meters under the pavement there appeared the walls of an immense tomb, the vastest that has thus far been recovered of the old empire. Several months were necessary for the excavation of the 31 rooms comprising the sepulchral temple of the family Meru-Ka. The rooms of Mera were cleared one after the other, as well as the monumental steles, the statue of the deceased, 2.30 meters high, and the sacrificial table. Then came the rooms of his son, Teti Mera, and those of his wife, Sech Secht, a royal princess.

Up to the date of the discovery of the tomb of Mera the most considerable tomb of the old empire, excluding the pyramids, was that of Teti, composed of two chambers, a stairway, and a court. The bas-reliefs of that tomb were considered the grandest productions of the old empire.

The discovery of the mastaba of Mera proves that all the tombs of personages of the earlier dynasties were constructions of the greatest importance, and that the tomb of Teti is far from being an exception. In that of Mera the walls are ornamented with sculptures and paintings of great delicacy. The scenes are of infinite variety—games, rustic employments, education, navigation, all kinds of occupations are painted with that ingenuous grace which the artists of ancient Egypt alone possessed.

To the east of the tomb of Mera, but always beyond the avenue of the Sphinx, my workmen discovered another monumental tomb, that of a certain Kabi-n, five chambers of which were cleared. This temple is far from being entirely excavated, but the exhaustion of my pecuniary resources in 1893 obliged me to suspend the researches.

The painted bas-reliefs that ornament the walls of this mastaba are the most remarkably executed of any that I know of the old empire. Unfortunately, in spite of a very active watch day and night, vandals, who remained undiscovered in spite of all inquiries made by our watchmen, defaced some of these splendid works of art with a knife. This act of irreparable vandalism ruined one of the best specimens of the art of

bas-relief. I almost regretted that I did not follow the plan of Mariette and cover the recently discovered monuments with sand, to protect them against the depredations of the fellahin or of certain visitors.

During the same excavations I examined numerous pits of different epochs. They have furnished many objects for the galleries of the Museum of Gizeh.

To the west of the pyramid, on the edge of the desert, there is a singular construction, of which, up to the present, no one had taken notice. Buried under the sand, it presented the aspect of a large rectangle, with the sides marked by a slight elevation of the soil. This inclosure, formed of four walls parallel throughout, measures 655 meters in length and 400 meters in breadth. A series of borings enabled me to recognize its nature and exact dimensions.

The interior shows no trace of a monument and no vestige of habitation; the virgin soil covers almost the entire surface. Some pits, found empty, were the only results of several hundred drillings executed in an area of about 26 hectares. Judged by the construction of the surrounding wall, this monument belongs to the earliest time of the Egyptian dynasties. Yet, although we know its epoch approximately, we have no facts as to its use and any conjecture is possible.

As I have already remarked, this large inclosure never contained constructions or habitations; it was no doubt built for some other purpose, and I am of the opinion that it bounded a surface occupied by immense subterranean structures. The examination of the entrance, however, will involve great difficulty and considerable expense.

Although the necropolis of Saqqarah has been for many centuries exploited for mummies, and during the last hundred years many times explored from the scientific point of view, yet the last word has by no means been spoken about it. In one year it has furnished documents of inestimable value and its sands still hide many scientific treasures. I have begun a map of this vast necropolis on a scale of 1:1250, a work which will occupy several years.

Dahchour.—During the summer of 1893, although I was detained in the desert by excavations in the necropolis of Saqqarah, I had the leisure to carefully study the environs, and, in taking up a map of the entire plateau, I examined most minutely the different regions of this vast necropolis, which extends without interruption from the pyramids of Abou-Sir to those of Menchiyèh.

This plateau is situated at a mean altitude of 35 meters above the valley of the Nile. It incloses several groups of sepulchers, of which only the most important, that called Saqqarah, has been the object of profound scientific research.

To the south the necropolis is terminated by the plateaus of Dahchour and Menchiyèh, where 4 large pyramids rise, 2 of stone and 2 of brick. Here and there masses of white stone proclaim the existence of ruins buried under the soil, but in most cases there was to be seen only

the wind-driven sand of the desert, which, at first sight, seemed never to have been touched by man.

A more attentive examination quickly showed me that the so-called desert contained a number of sepulchers, which, if not as numerous as those of Saqqarah, were at least as important.

The stone pyramids of Dahchour, although opened, yielded no historical information; those of brick had resisted all attacks. Only some ruined mastabas of the fourth and twelfth dynasties were known, the former situated north of the northern brick pyramid, the other south of the southern pyramid.

The absence of documents, the resistance which the pyramids of brick offered, the numerous indications which I discovered at each foot of the soil, were the reasons which induced me to concentrate my efforts on that part of the Memphitic necropolis. But being obliged to go to upper Egypt during the months of December, 1893, and January, 1894, I could direct the work in person only after the 18th of February.

During my absence excavations had been carried on according to my order to the south and north of the northern tumulus in the group of tombs, the upper of which I recognized on my arrival to belong to the old empire, and the lower to the twelfth dynasty.

The cartouches of Ousertesen II and III and Amenemhat III left no doubt as to the epoch in which these latter monuments had been constructed.

The pyramid, as I have already said, had been attacked, and under the millions of accumulated bricks untouched diluvial gravel had been found. The royal chamber was not included in the mass of the monument itself. As is usually the case in stone pyramids, it was possibly built deeper down. I soon learned by using the drill in the center of the trench recently opened, that the diluvium continued to a depth of 9.50 meters underneath the foundations of the pyramid, and was without the slightest trace of human labor. Under these alluvial deposits friable gravels were found whose silicious nodules arrested the drilling. Further search was useless, for the tombs, if they existed, would have been hollowed from the mass of the rock itself, and would probably be found at a very great depth.

These negative indications were most precious to me, and in order to procure information of a nature which would aid me in my researches, I abandoned for several days the excavation in the immediate neighborhood of the pyramid and devoted myself to a careful study of the tombs hollowed out in the mountain.

The tombs of the middle empire in the necropolis of Dahchour do not at all resemble those of the old empire, discovered by Mariette at Saqqarah. We do not find among the monuments of the twelfth dynasty at Dahchour the elaborate funeral temple covered with bas-reliefs like those of Ti, Mera, Ptah-Hotep, Ptah-Chepses, etc. The mastaba of Dahchour is very simple and contains no chambers, being

composed of a massive square of unbaked bricks, often very small. It is whole and is covered with a casing of the white limestone of Tourah. It was in the casing that the steles were found. They look to the north or the east, and are provided with tables for offerings. The pit is generally placed at the north of the mastaba, instead of opening in the center of the construction, as is usual in the tombs of the old empire, but the galleries are hollowed out in such a manner that the deceased reposes directly under the stele which bears his name. The corridors that lead to the funeral vault are cut in the rock and are covered either by an elliptical arch of rectangular sections of Tourah limestone or with an arch of unbaked bricks fitting very regularly and slightly raised.

These observations concerning the tombs of the twelfth dynasty in the necropolis of Dahchour result from the opening of thirty mastabas. I have, therefore, certainly not been led into error by an anomaly in the funeral usage.

The construction of the pyramid and of the mastabas presents striking analogies. The bricks are identical in dimensions, material, and making; the dressing is the same in the great monument as in the small ones. It is easy to conclude from these likenesses that all the tombs belonged to the same epoch. At the same time I observed that the masses resulting from the pits of the mastabas formed around the excavations from which they proceeded regular layers, more or less thick and interspersed among the sands produced by the wind, and that in consequence when I encountered the débris I necessarily discovered the exits not far from the pits.

While I was concluding these studies, the researches which I had caused to be executed on the base of the pyramid in the supposed place of the lining on the north and east ends led me to discover stones decorated with fragments of inscriptions. One of them contained the cartouche of Ousertesen III. This discovery rendered my conjecture as to the age of the pyramid a quasi certainty.

I then began the examination of the pits in the open space between the foot of the pyramid and its inclosure of bricks. After a large number of diggings with the pickax in the made soil down to the diluvial gravel, I found the remains of a deep excavation hidden under the sand. Following these remains, I came gradually to the mouth of a pit (February 26) situated near the northwest corner of the pyramid.

Two days were necessary to remove the earth which filled the cavity. In the course of the work a poor little grave, dated in the twenty-sixth dynasty, placed in the ruins which inclosed the pit, was discovered, and on the 28th of February the door of the subterranean structure was found.

A tortuous way descended with a gentle slope toward the pyramid and came to an end in a funereal chamber vaulted and ornamented with white limestone where, amidst the débris of a stone sarcophagus,

lay the remains of a diorite statue. It had been entirely broken in this vault; the pit through which I had entered was probably the same one used by some earlier spoilers of antiquity, in all likelihood as early as the period of the twenty-sixth dynasty.

This first sepulcher opened into a passage 110 meters long, running from west to east, and consequently parallel to the north façade of the pyramid. Doors made of Tourah limestone opened into the northern sides of this gallery. Everything had been turned upside down and the sarcophagi had been opened, but the inscriptions which they bore informed us that in the second vault a queen named Nefert-hent had been buried. Among the broken flagstones and rubbish were found skulls, canopies, and vases of clay and alabaster. Everywhere the greatest disorder reigned, and the white walls here and there still showed traces of the hands of the spoilers.

This first visit made, I immediately ordered workmen to clear the principal gallery, and the soil was distributed over the entire length of the subterranean structure. A wall of freestone was met, and I found on the other side definite indications of the existence of another pit. It was about time for the discovery of that egress, because air was wanting in the gallery and the lights were extinguished. I immediately made a plan of the subterranean structure, and carrying it back to the surface, fixed the point of the opening. This pit was cleared in a few days. It opened near the northeast angle of the pyramid, rendered possible the discovery of tombs heretofore unknown, and created a current of air, without which it would have been impossible for the laborers to complete the work.

Twelve sarcophagi of princesses had been successively discovered and the clearing definitely commenced. I had given precise orders that the explored portions of the tomb should be freed from all the débris in order that the rock could be seen in place.

As I had the honor to tell you, the sarcophagi had all been despoiled; but the searchers after hidden treasures had evidently been hasty in their work, for a goodly number of stone chests containing canopes had been respected, and some chambers were still closed by the walls of brick. On the 6th of March the first treasure was discovered. The jewels inclosed in a little box inlaid with gold and silver had formerly been buried in the soil of the gallery at a depth of about 40 centimeters, near the door of the tomb of Princess Hathor-Sat. The following day, the 7th of March, another hiding place was found in a neighboring gallery at the foot of the tomb of Princess Sent-Senbets. The ancients, foreseeing that spoilers would later come to destroy these tombs, had taken all precautions to hide from their eyes the most precious jewels.

The richness of this treasure is considerable; necklaces, bracelets, rings, mirrors, breastplates, pearls, pendants, jewels of every sort, were found by the hundreds in the holes in which they had been hoarded up. The chests had been destroyed by the humidity, and their riches lay pellmell in the midst of the sands and the débris.

Nearly all the jewels are of gold, often inlaid with precious stones; others are of amethyst, carnelian, turquoise, or lapis lazuli, cut in the form of scarabs, pearls, and pendants, and often set in gold. The mirrors are of silver or bronze, mounted in gold; the vases of alabaster, carnelian, lapis lazuli, and obsidian, frequently having gold mountings.

The workmanship of the jewels is exquisite in form, precision, and especially in the composition of designs. The inlaying and the carving are especially beautiful. All this denotes an extremely advanced civilization, more developed than it was possible to suppose from what we know about the twelfth dynasty. It would be impossible for me to describe in detail all the forms and particulars of each one of the jewels. I shall content myself by noting the principal objects, those of the greatest historical or artistic importance.

In the first treasure I found a breastplate in gold, enriched with precious stones and representing the cartouche of King Ousertesen II supported by two crowned hawks, two bracelets, several clasps of necklaces, all in gold. inlaid with lapis lazuli, carnelian, Egyptian emerald, turquoise, and obsidian (?), and several scarabs, one of which contained the name of Ousertesen III, and another that of the Princess Hathor-Sat. These two scarabs are veritable marvels, both because of the material of which they are engraved—they are amethyst—as well as because of the workmanship. Other objects discovered were six crouching golden lions with collars made of pearls of gold, amethyst, and lapis lazuli; large golden shells, figured with cypresses, others representing pearl oysters; a golden collar; a mirror of silver enriched with gold; and a lot of small objects of the most perfect workmanship.

The second treasure is much more important than the first, and includes several hundred objects, among the choicest of which I will mention a breastplate of gold enriched with stones. In the center is the cartouche of King Amenemhat III. On both sides the king is seen, upright, raising his club and striking an Asiatic captive, designated by a text at the side, and above a vulture soars with outspread wings. The reverse contains the same representations in chased gold; the inlaying of this piece is on lapis lazuli, Egyptian emerald, feldspath, turquoise, carnelian and black obsidian (?). These gems are not only cut in the requisite forms, but are also so delicately engraved that the heads of king and of captive and the bodies show in relief the smallest details. Another pectoral of the same king bears his cartouche, supported by two griffons. Four captives are figured on this jewel, two Asiatics and two negroes. On the reverse are the same scenes engraved in gold. These two pieces, of first importance, are, with the pectoral of Ousertesen II, the finest jewels discovered, and the next in rank are the inlaid bracelets containing the cartouche of Amenemhat III. There were also found numerous scarabs with the names of kings and princesses; three mirrors, two of them of silver with gold mountings; a collar of lion heads, joined together in fours, each pearl of the collar as large as an egg; shells of gold as large as the lion heads; clasps of collars

enriched with gems; collars of gold, amethyst, emerald, and lapis; a pearl of glass; four couching lions in gold, etc.; vases of carnelian, lapis lazuli, obsidian, and alabaster, some of them enriched with gold; and many objects of less historic interest, though not inferior in workmanship to the great pieces, conclude the list of the find. The perfection of the handiwork and the state of preservation are especially striking in these treasures. No enamel has fallen off, no shock has in the least destroyed the most delicate work, while the technique of the jewelry is so perfect that nothing could surpass it.

After the discovery of the treasures, the work was actively continued and all the environs of the northern pyramid were literally riddled by diggings over a surface of about 6 hectares.

These researches led to the discovery of a large number of pits of secondary importance, and finally to the finding of five large wooden boats 10 meters in length.

While I was exploring the surface I was likewise engaged on an underground gallery, which, parting from the eastern pit of the princesses, proceeds toward the center of the pyramid through the sand bed which forms the subsoil. Already 140 meters of the principal galleries has been hollowed out without finding the royal tomb. A vertical distance of 10 meters has been explored. The excavation of the approaching season will certainly yield results worthy of attention.

In the surrounding wall of the northern pyramid I discovered over the tombs of the principal princesses the ruins of crude brick mastabas, entirely similar to those which the first diggings brought to light. Near these ruins, in the surrounding débris, I found several fragments of bas-reliefs bearing the title of "Royal Daughter." There is, accordingly, no doubt that these mastabas were formerly funeral chapels of princesses.

Two deep pits, a little north of these monuments, each inclosed a sarcophagus of alabaster, superb pieces of stone, probably taken from the quarries of El-Amarana. Unfortunately they had no inscription. One of the two contained four empty alabaster vases.

To the south the excavators brought to light three large mastabas of unbaked bricks, situated in the inclosure between the wall and the foot of the pyramid, some fragments of bas-reliefs, and two pits, one of which inclosed anonymous canopes, placed in a granite chest.

In the southern part of the necropolis, near the village of Menchiyèh, I commenced, on the 10th of April, an examination of the soil comprised within the inclosure of the southern pyramid. In the initial work I came across fragments of bas-reliefs with the name of Amenemhat III, of the twelfth dynasty, probable successor of Ousertesen III; then, proceeding methodically, I made borings in the ground in the same way that I had examined the surroundings of the northern pyramid.

On the 17th of April a pit was discovered within the inclosure, near the wall, in the prolongation of the eastern side of the pyramid. In

removing the ruins a statuette of gilded wood was found whose base bore the inscription "The son of the Sun, issue of his loins, Hor," and then fragments of alabaster vases bearing the second name of the King Fou ab Ra or Aou ab Ra.

No king of this name was hitherto known in the twelfth dynasty. There were in the thirteenth two kings of the name of Aou tou ab Ra; but it seemed scarcely possible to assimilate these two names, even if Aou ab Ra had been found buried in the territory reserved to the princes of the twelfth dynasty.

The researches speedily brought to light the funereal vault; it had been despoiled, having been entered by a hole made in the ceiling. It was in this way that I entered, myself, as soon as the opening was freed from the ruins which obstructed it. The chamber was empty, and great disorder reigned; boards, chests, pieces of alabaster, and fragments of vases encumbered the funereal vaults. The sarcophagus had been opened, its cover laid at its side, as well as that of the wooden coffin on which could be read, engraved in gold leaf, the names and titles of the king. Near this was an inverted naos, its face in the air, covered with inscriptions painted in green on a golden ground. The interior inclosed a large wooden statue, decorated with gold, canes, scepters, a large number of offerings imitated in wood, and fragments of alabaster vases with royal cartouches. The thieves had carried away only the most precious pieces, abandoning all these objects which are to-day of such great value to us.

The inscription on the façade of the naos is as follows: "Horus Hotep-ab, the master of the diadems of Vautour and of Uræus. Nofer-Khaou (of the splendid apparitions), golden Horus Nofer-Nouterou (beauty of the gods), King of upper and lower Egypt, master of the two lands, the Almighty Aou ab Ra (or Fou ab Ra), the son of the Sun, the issue of his loins, whom he loves. Hor, the royal double living in the tomb; he gives life, stability, force, and health; he rejoices himself on the throne of the Horus of the living, like Ra, the everlasting."

Two square steles, engraved on alabaster, and an offering table furnish religious texts, all in the name of the king, whose cartouches are repeated twenty times.

The royal mummy was inclosed in a case worked with gold, as was also the lid, and covered with texts. It had been despoiled, but during the researches I found some interesting objects. A mask in the form of a klaft covered the head of the king; on his left were scepters and the débris of his flagellum, of small alabaster vases, and other minor objects. To remove this material it was necessary to open the original gate, the entrance of the spoilers being insufficient. This work took two days, because the natural rock is very dangerous in that place and great precautions were necessary. I and my workmen were almost crushed by a slip in the pit.

As soon as the vaults were freed from the objects which surrounded them, I proceeded to a careful examination of the pavement and of the

walls, and under a block of stone I came across a chest containing canopes. This chest, which had not been touched by the robbers, was, like the coffin, covered with gold leaves with the titles and names of the king. A string which fastened it still contained his seal in clay. The seal showed the name of Amenemhat III. It was, however, the sovereign who presided over the funeral rites of the king, his predecessor or his coregent, unknown hitherto.

This verification is of the greatest historical importance, because it proves either that there was a king between Ousertesen III and Amenemhat III, or that Amenemhat IV did not reign alone. Not only does it definitely fix the epoch or age of King Hor, but it also assigns him a rank in Egyptian chronology.

The tomb of King Hor is situated, as I have said, outside of the pyramid, in the northern part of its surrounding wall, and for this reason it is not the tomb of the king who built the colossal brick structure. This fact is interesting, but it is still more curious to find a king interred in a modest tomb; his vault is very restricted indeed, and would seem rather to be the last habitation of some private individual than that of a master of Upper and Lower Egypt. A problem still remains whose solution will probably be furnished by a continuation of this work.

The diggings which followed led to the discovery of eleven other pits running from east to west. Some had fallen in and seem never to have been finished; but one, the nearest to the royal pit, has furnished very important results.

On the 19th of April, when this pit was emptied, I came to a door giving access to a passage 14.60 meters in length and covered with a cylindrical arch, properly joined. This gallery, in every way resembling that leading to the royal tomb, was broken in the middle by a very dangerous cavity, which required much care. It ended southward in a wall, constructed of the stone of Tourah, closing the door of the vault. This tomb had not been violated.

I think it useful to insist here upon the existence of arches of crude brick in the tombs of the twelfth dynasty at Dahchour. I have thus far met several of which the oblique cut relative to the axis denotes a very extended practical knowledge on the part of the architects of this epoch. Another remark must also be made on the subject of the employment of plaster, which is general in the monuments of Dahchour. I myself have found in the various constructions vases in which the mortar had been tempered; one still sees the thumb mark of the masons traced in the wet mass.

The door was opened with all the precautions necessitated by the bad state of the gallery, and as soon as the first stones were taken off we saw before us all the objects placed in a small room, in the spot where they had been deposited by the priests of the twelfth dynasty or by the family of the deceased. There stood the clay vessels still inclosing the mud of the Nile water; here pieces of embalmed viands; a

little farther the dishes with dried food. In a corner there were two cases; the one inclosed perfumes in alabaster vases, carefully labeled in hieratic characters, the other contained scepters, canes, a wooden mirror, and arrows whose points were astonishingly well preserved.

Thus far it is impossible to say whether this tomb was that of a man or of a woman. It contained arms and toilet objects. The only indication we found was the seal with which the perfume chest had been sealed: it bore the family name of King Tesch Senbet. As soon as all these objects were numbered, and when their respective positions had been sketched. and when finally that chamber had been emptied, the opening of the sarcophagus commenced. Large flags of white Tourah limestone covered the entire floor of the chamber of offerings, forming at once the floor of that chamber and the cover of the sarcophagus.

As soon as the first stone had been removed there appeared a wooden coffin, gilded. decorated on both sides, and ending in a slope. An inscription in gold reached the whole length of the cover. It gives us the name and the title of the deceased; the princess (or royal daughter) Noub Hotep ta Khroudit.

The case of the coffin, also decorated with gold leaves, was made of natural wood; the golden bands bearing the inscription were inclosed in a line of green paint. The inscriptions of the coffin were immediately copied, and then detached with the greatest care, for the paste which held them crumbled, so that they fell off at the slightest shock, and it was impossible to transport them with the wood. The mummy, although untouched, had suffered very much from moisture, and nothing remained but a mass of bone, jewels, and dust, inclosed in the remains of an envelope of plaster, entirely gilded. But the objects had not been displaced at all, and by removing them carefully it was easy to find the use to which each part was put.

On the left were the canes, the scepters, the flagellum, and a curious instrument, frequent in the bas-reliefs of temples, but never before found in so complete a state. On the head of the royal mummy there was a diadem of silver inlaid with stones, an uraeus, and the head of a golden vulture. On the breast I found a necklace decorated with about fifty pendants of gold, inlaid and terminating in two heads of golden hawks of natural size. Toward the waist there was a poniard with a golden blade, and on the arms and feet were golden bracelets ornamented with pearls, carnelians, and Egyptian emeralds.

I shall not dwell on the description of these funereal trappings; the jewels, though very heavy, are of inferior workmanship compared with those of the preceding discovery. The inlaying and embossing are comparatively crude.

The head of the mummy was, as usual, placed at the north of the tomb; on the left of the feet was a box of canopes, worked with gold like the coffin, and covered with texts.

Among the titles of the Princess Noub Hotep it is never mentioned that she had been queen, and yet I found in her tomb all the attributes

of royalty. Perhaps she died before the accession of her husband to the throne, and he was therefore only the heir apparent.

The tombs of King Hor and Princess Noub Hotep, as well as the details of their funeral furniture, show clearly that these two persons had been buried at the same epoch. Must we hold that the princess was either the wife or the daughter of the sovereign near whom she reposed?

At the same time that these researches were being made I prepared a very detailed account of their results. This description will be contained in a special volume, in which all the objects, texts, plans, and the details of architecture will be figured. M. G. Legrain and M. G. Jéquier, members of the French Oriental Institute of Cairo, aided me in their composition, the Egyptologists of the Service of the Antiquities being busy either in the museum at Gizeh or in other researches in progress in various parts of Egypt.

After these discoveries I continued the exploration of the soil included in the surrounding wall of the southern pyramid. The shapeless remains of the mortuary chapel which formerly stood to the east of the monument were brought to light; but the entrance of the subterranean structure still remains hidden. In the south, as well as in the north, it will be necessary in future researches to proceed by means of mined galleries. But while the northern pyramid reposes on solid stones, that of the south is constructed of crumbling clay. The galleries ought to be wainscoted, a task which, without skilled workmen, will require much care. East of the pyramid extends a large square filled with tombs of the principal functionaries of the king, who is buried in the pyramid. The exploration of this necropolis will form a part of the next research campaign.

Fayoum (1893–94).—The Roman necropolis of the Fayoum, so often explored, still retains an appreciable number of interesting documents; about fifteen mummies decorated with portraits, an incense box in gilded wood—a unique object and in a perfect state of preservation—several sarcophagi, and some inscriptions of the Roman epoch were found.

Meïr (1892, 1893, and 1894).—The necropolis of Meïr was as yet almost untouched. I signalized my arrival in the Service of Antiquities by having researches made on it, and the three campaigns which followed have been fertile in results. In September, 1892, the tombs of the twelfth dynasty yielded us some curious wooden statuettes and one in bronze of a person named Nakht. This last is a unique piece, being duly dated. Twenty-eight wooden boats, some of which still have their sails, accompanied the statuettes.

In 1893 the discoveries continued, the objects found also belonging to the twelfth dynasty.

In 1894 a tomb of the sixth dynasty was opened. It contained a series of most original statuettes, representing the servants of the deceased engaged in the ordinary duties of life. There are women kneading

bread, others putting it into the oven, reapers, fruit merchants, armies of slaves with fans to drive away the flies, and also the special servant of the deceased bearing his effects.

This fortunate discovery revives for us, in the form of statuettes, all the scenes we are accustomed to see figured in bas-reliefs on the walls of the mastabas of the ancient empire.

Siout (August, 1894).—Since my departure from Egypt, having stopped the diggings of Dahchour in order that I might renew them myself the coming winter, the efforts of the Service of Antiquities were turned toward the necropolis of Siout, and a remarkable discovery was made there. All the tombs of that necropolis thus far known have been violated by searchers after treasures; only one, which had just been brought to light, had escaped their hands, and it gives us most interesting information about a period of Egyptian history concerning which very little is known. The body had been placed in a double rectangular case of acacia wood, similar to those of the necropolis of Dahchour; the inscriptions traced with ink on both sarcophagi give us, besides the usual religious formulæ, the name and title of the deceased; "the feudal prince, chief of the prophets of Ouap ouaïtou, lord of Siout, royal chancellor, Emsah." The mummy, reduced to a skeleton, was enveloped in raw linen, and had on its head and breast a wooden mask; various objects reposed on the deceased or at his side; a silver collar, a mirror, a pillow, sandals, a basin of bronze, canes, bows, a scepter, *ouas.* But the most interesting objects are those which had been deposited at the side of the sarcophagus, and first of all a funeral bark, 1.20 meters in length, giving us the exact model of a dahabieh of the epoch, with its mast in the bow and in the stern the double cabin with its walls and its roof, built of light timber, where the deceased and his family stay, while the crew stand on the bridge in poses full of grace and naturalness. On either side of the coffin are soldiers of the deceased to the number of eighty, in two groups, well ordered, and showing us an army highly organized. First of all are the Egyptians, dressed in short aprons and armed with large, light shields and lances with great bronze points, while the negroes on the other side, clad still more lightly, each carry a large bow and half a dozen arrows with blunt points. All these persons in wood, so carefully made, about 40 centimeters high, show us the forces which the princes of Siout had at the disposal of the Heracleopolitan kings in those long civil wars which desolated Egypt during the ninth and the tenth dynasty, contests of which the tombs of the other princes of the Lycopolite nome speak, among others Khiti, who has given us on one of the walls of his tomb the representation of these same soldiers.

Gaou (1893).—These excavations have brought out mummies of the Greek epoch of moderate interest, some small monuments, such as funeral statuettes, winged scarabs, etc., of fairly good workmanship, and a cover of a compact limestone sarcophagus, similar to those discovered at Saqqarah. It is very well made. The inscriptions are

painted in green, the eyes are inlaid, and the face gilded. (Ptolemaic epoch.)

Gournah (January–April, 1894).—The campaign at Gournah was one of the least productive. Its yield consists of two pits each inclosing a sarcophagus, without importance, of a priest of Ammon. A covered tomb with fine paintings was also cleared, but I was obliged to fill up the entrance.

Karnak.—Two colossal statues were removed from the temple of Karnak and are now deposited in the museum of Gizeh. The one, in solid sandstone, represents King Seti II (nineteenth dynasty). It was placed in the hypostyle under the débris of a pylon. The waters covered it every year. The other, located in 1892, is of rose granite. It was placed near and facing the great pylon. It represents a certain Amen-Hotep, scribe of the eighteenth dynasty.

Gebelein (March, 1893).—These excavations have not yielded notable results. They have revealed some fragments of a monument of the eleventh dynasty and a stone bearing the cartouche of King Khian.

Hassaya.—The Græco-Roman necropolis, which seemed to be exhausted, has, however, produced many Greek or Egyptian steles of the latter epoch. Two seasons of excavation have been had at this point, one in April, 1893, the other during the early months of the year 1894.

Kom-Ombos.—While I was occupied with the clearing of the temple (January–March, 1893), I had some excavations made in the necropolis, where I established the existence of numerous sepultures of the Ptolemaic epoch of little interest. Besides, I found in tombs, similar to those of human mummies, a mass of animal mummies. They included snakes, mice, hawks, gazelles, rams, and more often crocodiles, some of which have a length of 5 meters.

Assouan (January, 1893).—Several tombs belonging to the sixth and the twelfth dynasty have been discovered. They contained only objects of little importance.

Island of Sehel.—While we were uncovering all the monuments of that region, for the purpose of preparing the first volume of the Catalogue of Monuments and Inscriptions of Ancient Egypt, I discovered the ruins of a chapel dedicated to the goddess Anoukit. Unfortunately this little monument is destroyed in such a manner that it has not been possible to recover its primitive function.

THE CLEARING AND STRENGTHENING OF THE MONUMENTS.

Gizeh.—The temple of the Sphinx, long since discovered, had been entirely cleared by Mariette. But since that time the sands of the desert, driven by the wind, have accumulated and obstruct more than half of the monument. These chambers were again cleared up during the summer of 1892, and are open to the public.

Abou-Sir (August–October, 1893).—The mastaba of Ptah-Chepses, recently discovered, has undergone the most necessary repairs. Two

chambers have been restored, recovered, and provided with grates. The grand court still lies under the débris.

Saqqarah (July–August, 1892).—The grand court of the tomb of Ti has been cleared anew, as well as the pit and the galleries leading to the chamber of the sarcophagus. The court is at present screened by a ceiling and lighted from the center in such manner that the visitor may traverse all the chambers of this celebrated tomb.

(August–October, 1893.)—The tomb of Meru-Ka, called Mera, has been entirely repaired, and, immediately after being brought to light, so well covered up that its thirty-one chambers have been open to the public since the beginning of the season of 1893–94.

(September–October, 1893.)—The mastaba of Kab-in, near that of Mera, having been only partly cleared, the five chambers discovered have been repaired and covered with a ceiling, an improvement being effected at the same time in the tombs of Ptah-Chepses and Mera.

Luxor.—The clearing of the temple was actively pushed under the direction of M. G. Daressy, assistant conservator of the Service of Antiquities. Commencing on the 1st of January and finishing at the end of April, they continued work on the large colonnade on the court yard of Rameses, the northeast angle of which could not be touched because of a mosque which occupied it, and on the exterior of the temple in the southeastern part, the only place where it was possible to work, the other environs of the monuments being encumbered with houses. By a Khedivial decree of 1894 all property comprised in the surrounding wall of the temple is to-day considered public property, but the condemnations are not yet operative. The mosque which for more than ten years had been the principal obstacle to excavation is also destined to be transferred. A large structure of masonry was erected to repair the columns and the different parts of the temple, as well as to create a wall around the monument. Two vaulted drains have been constructed to permit the waters of the Nile to enter and freely discharge. This measure has been taken to carry off the salt with which the soil and the constructions are impregnated, and which by their crystallization and their dissolution every year disintegrate the particles of the materials of which the edifice is composed. All the earth taken from the temple has been transported, at the expense of the inhabitants of Luxor, to the ponds situated northeast of the village. It is a very useful measure for the health of the locality.

Ombos.—The temple of Ombos rises on the summit of a small mountain, situated on the right bank of the Nile, 40 kilometers below Assouan. In earlier times this temple was entirely surrounded by water. To day the right arm of the river is entirely filled up.

At Kum-Ombos, as at Philæ, the outer works of the temple reached as far as the banks of the Nile, but the current has washed them nearly all away and would have inevitably destroyed the other monuments if I had not taken the necessary measures to protect them in the future.

A wall of crude bricks, three sides of which are still well preserved,

circumscribed the grounds reserved for the worship and the priests. In the midst was the large temple, its façade turning toward the west. At the northwest was the mammisi; at the southwest the pylon. Between the two are the remains of a sakieh which furnished the necessary water for the temple. The large monument is composed, a fact unique in Egypt, of two temples joined following their axes. The sanctuaries are independent and the gates of the façade are double. One of the sanctuaries, that of the south, was dedicated to Sebek or Sobkou, while that of the north was dedicated to Haroëris.

The sovereigns who contributed to the embellishment of the temples of Ombos are Ptolemy VII, who seems to have built the greater part, the Ptolomies IX, X, XIII, and the emperors Augustus, Tiberius, Caligula, Claudius, Nero, Vespasian, Domitian, Antonius, and Commodus himself, whose cartouches are found in the exterior buildings.

There is no doubt that most of these sovereigns of the west completely ignored the existence of the little town of Ombos lost in upper Egypt, but their names are engraved on the monuments and furnish us the date of the constructions.

From the picturesque site on which it rises, from its singular architecture, and the delicacy of the sculptures covering its walls and columns, the Temple of Ombos especially recommends itself to the attention of visitors.

Nearly all the scholars who have visited Egypt declared that the temple was destined to be destroyed, and this opinion seemed very just, because the river ate away each year a new part of the kom; but I was resolved to try all efforts to save this monument, unique of its kind in the valley of the Nile, from destruction.

It was the 1st of January, 1893, that the excavations began; in three months more than 25,000 cubic meters of earth were removed and cast into the Nile. The stones bearing no inscription, which had fallen into the midst of the building, were employed in the construction of a solid buttress that now protects all the ruins against the current of the river. One after another, each column, each architrave, each wall, has been carefully strengthened, so that by the 1st of April the most important work had been finished. The excavations were taken up again in October of the same year. The area of clearing was extended, and thus 25,000 cubic meters additional of sebakh and of sand were taken out from the perimeter of the edifice. A wall of crude bricks was constructed all around the monument, to keep up the grounds of the kom and to protect the entrance of the temple.

To-day the ruins of Ombos are saved forever; it will be sufficient to maintain the protective works. The buttress on the Nile has already resisted two overflows without the slightest settling.

Assouan.—I speak only from memory of the works partially executed in the necropolis of Assouan, as well as of those effected in Medinet-Habou, in Denderah, and in Abydos, by the searchers of sebakh operat-

ing under the direction of our inspector. Considerable blocks of earth have been taken away without any cost to the Service of Antiquities. The complete clearing of these monuments is only a question of time.

MUSEUMS.

On my arrival in Egypt there was but one museum, that of Gizeh, situated about 2 kilometers from Cairo, on the left bank of the Nile, and occupying the vast halls of the palace built by the Khedive Ismael Pacha.

The transport of the antiquities from Boulak to Gizeh had been entirely effected, but all the monuments were far from being exhibited. I at once employed all of my resources for the definite organization of the galleries. In six months 46 new halls were installed, and the empty stone room harbored only fragments unworthy to be placed under the eyes of visitors.

Into the galleries of the ancient empire a goodly number of colossal steles were brought from Saqqarah, where they had been hidden under the sands since their discovery by Mariette.

To provide for these expenses I was obliged the first year to slacken a little the work of excavations, or rather to reduce them as much as possible. To meet all these charges I had only the ordinary budget for researches, reduced by 1,500 Egyptian pounds, on my arrival.

While this organization was being effected I had time to examine attentively the building in which so many treasures were deposited, and I quickly became convinced that it was quite impossible to protect the palace against the dangers of fire. It was then, for the first time, that I gave my official advice to the Egyptian Government on this important question. The danger was real; everyone gave heed, and quite recently (July, 1894) the Council of Ministers voted a sum of 150,000 Egyptian pounds for the construction and fitting up of a special building in the city of Cairo.

The building and arrangement of this museum is placed under international control, so we have reason to hope that the year 1897 will not pass without seeing the Egyptian antiquities protected from every catastrophe.

For a long time the city of Alexandria, the capital of the Ptolemies, claimed the right to preserve within its walls the vestiges of its ancient grandeur; but administrative difficulties of every kind opposed the realization of this project. Taking up the matter anew, I have solved the problem; to-day a Græco-Roman museum collects the Alexandrian antiquities under the direction of the General Service of the Antiquities of Egypt.

The director of the new museum, M. G. Botti, a very capable archæologist as well as a good Hellenist, devotes all his activity to the study of the ancient city of the Ptolemies and Romans. The museum of Gizeh

has already forwarded to him important series of papyri and antiquities of epochs concerning it, and I do not doubt that in a few years the new building which the city is going to construct will be too small to contain the collections.

Before May 1, 1892, the museum of Gizeh included only 45 halls; to-day it counts 91. That of Alexandria has 10. This gives for all Egypt a total of 101 exhibition halls, 56 of which have been created within two years without special appropriations.

In finishing this outline of the actual condition of the museums, I have to express to my collaborators my gratitude for the devoted efforts they have never ceased to accord to this work. Messrs. E. Brugsch-bey, H. Bazil, G. Daressy, Ahmed-bey Kiamal, A. Barsanti, and G. Botti have rivalled each other in ardor and zeal to promote this very complex work.

PUBLICATIONS.

Since its establishment the Service of Antiquities has had no special publications. The various directors, who, beginning with Mariette, have succeeded each other in Boulak and in Gizeh, have given an account of their labors in personal publications; but, thus far, the Museum of Egyptian Antiquities possessed no annals.

It was necessary to publish accounts not only of the monuments which remained standing throughout Egypt, but also of the treasures exhibited in the museums and the results of the excavations. This extensive work could not be accomplished by a single man; the personnel of the service was not sufficient for so great an undertaking. I have accordingly invited all Egyptologists to lend their aid to the Service of Antiquities, thus founding an international publication edited by my administration. Our publications are divided into three series, as follows:

1. Catalogue of the monuments and inscriptions of ancient Egypt.
2. Catalogue of the museums of Egyptian antiquities.

The first series will embrace the publication in extenso of all the monuments still existing on Egyptian soil, and I can not better show the purpose of this work than by presenting to you the first volume, which appeared only a few months since. It gives a complete description of all the antiquities situated between the frontier of Nubia at Assouan and the Temple of Ombos.

Two other volumes are in press; they contain a complete description of the Temple of Ombos. We owe these three volumes to Messrs. U. Bouriant, director of the French Archæological Institute in Cairo; G. Jéquier and G. Legrain, members of that institute; A. Barsanti, conservator of the Service of Antiquities, and to my personal aid.

The second series will contain the catalogues of all the objects deposited in the museums. Several volumes are in preparation, as follows: The Greek papyri of the museum of Gizeh, by P. Jouguet, member of the French School at Athens; those of the museum of Alexandria, by

G. Botti, conservator of the museum; the steles of the middle empire, by Willoughby Fraser; those of the Ptolemaic epoch, by Ahmed-bey Kiamal, and the monuments of the Ramessides, by G. Daressy.

It should be noticed that foreign scholars unite in this work with the members of the Service of Antiquities. Each author is responsible for his publications, the Service of Antiquities contenting itself with putting all the memoirs in the same style of type, and with the execution of the volumes.

The third series will embrace only the description of the principal discoveries. I thought it necessary to preserve for science the details of the researches and discoveries, which unfortunately thus far have been too often neglected. This collection begins this year in a volume on my excavations at Dahchour, for which Messrs. Legrain, Jéquier, Loret, Fouquet, and Berthelot have been willing to give me their scientific assistance.

The first idea of these publications came to me on my arrival in Egypt, but I have had recourse to my collaborators, Messrs. U. Bouriant, G. Jéquier, and G. Legrain, to arrange the details for the execution of my projects. I can not sufficiently express my gratitude for their efforts and their judicious observations, of which the first result has been the printing of this volume from Assouan to Ombos, which I have the honor to offer to the congress.

These are the results of the efforts of the Service of Antiquities during these last two years. We wish, above all, to put at the disposition of scholars all the documents that will aid them in their studies. Our excavations, our clearings of monuments, our classification of the museums, and our publications have only this purpose.

WORK OF THE INSTITUTE.

Charged by the Egyptian Institute to represent it before you, I will retrace in a summary manner the work of this company since I have had the honor to take part in it.

Our institute has not, it is true, the pretension to rival the great scientific institutions of the world. It treats, only very rarely, questions of general interest; but it is attached to the soil of Egypt, examining it from every point of view, and in making the land of the Pharaohs known, to its slightest details, it responds to the expectations and hopes of its founders, Monge, Bonaparte, and that constellation of eminent men who for nearly a hundred years have opened to civilization and science these lands, formerly closed.

During the last two years technical specialists have furnished memoirs to the bulletin of the institute and all have related to Egypt. Dr. Schweinfurth has given us attractive studies on the geology and stratigraphy of the Egyptian soil; M. Piot, a curious thesis on the fossil bones of a kind of antelope which formerly lived in the desert.

Prehistoric Egyptian, or better, the practice of stone cutting in the

valley of the Nile has been the object of a minute investigation on the part of M. Lajard. Thus far researches of this kind have been unfortunately too much neglected. Chipped flint had been, it is true, collected in nearly every part of Egypt, but without having given rise to a complete work. We hope that M. Lajard, extending his investigations, will definitely fix the laws of the use of stone in Egyptian antiquity.

Egyptology has not been neglected in the institute. We owe to M. G. Daressy several important memoirs, and to M. Ventre-bey the raising of the question of the origin of the names of Memphis, of the pyramids, of the Coptic people, of Egypt and the Egyptians, of papyrus, and of the Nile itself.

M. Dutilh, specializing in numismatics, has read several communications of high importance on the unedited medals of the cabinet of Gizeh, deducing with singular sagacity and a deep knowledge of numismatics general questions of discoveries he had made on coins.

In an ingenious paper Dr. Fouquet presented to the institute specimens of the art of glass making, duly dated. One bore the cartouche of Amenemhat IV (twelfth dynasty), the other that of Thoutmes III (eighteenth dynasty). The special notions of Dr. Fouquet on the enamels and glasses of ancient Egypt have absolute authority, and his theories are of special interest.

The Christian epoch is represented by a treatise of Count Max de Zogheb on the history of the Church of Alexandria, a work of merit, honoring its author.

After the study of antiquity, for which I shall not omit the names of Messrs. Brugsch-bey, Groff, Ahmed-bey Kiamal, whose judicious and competent observations enlighten the discussions of the institute, I shall speak of the communications relative to the Mussulman epoch, a branch of archæology in which the institute counts works of real value.

His Excellency Yakoub-Pacha Artin, continuing his researches on Arab numismatics, has given to the institute a very remarkable memoir on the series of the Mahdi and of the Khalife Abdoullah.

Mr. Max van Berchem, apropos of the Corpus of Arabic inscriptions of Cairo, has presented to the institute a number of texts collected on the monuments of that city. This collection has a high historic interest, and placed in the hands of an Arabist, as distinguished as is M. van Berchem, it can only portend very happy results for the progress of the knowledge of the middle ages.

M. Max Herz, the capable director of the Arab Museum, pursuing his studies on the mosques of Cairo, has made the institute admire the pleasing effects of polychrome in Arab architecture.

This is the summary of the results of the labors of the Egyptian Institute during the two years just passed. All relate to Egypt, and though they cover a narrow area my colleagues easily find a purpose for their scientific activity.

REPORT UPON THE EXHIBIT OF THE SMITHSONIAN INSTITUTION AND THE UNITED STATES NATIONAL MUSEUM AT THE COTTON STATES AND INTERNATIONAL EXPOSITION, ATLANTA, GA., 1895.

By G. Brown Goode, LL. D.,

Assistant Secretary, Smithsonian Institution, in charge United States National Museum.

The exhibit made by the Institution was not as satisfactory as it was planned to be, owing to the small amount of money allotted for its preparation, transportation, installation, maintenance, and return. Had it not been possible to draw extensively from the exhibits of the Museum that were procured for and shown at the World's Columbian Exposition at Chicago and from the specimens of the Museum the exhibit would have been even less creditable. With such resources as were at my command, I am pleased to say that an exhibit was made which, although small, proved itself to be both attractive and instructive. In preparing it, however, the halls of the Museum were dismantled, the collections broken and disarranged, and the whole Museum building presented an untidy appearance during most of last summer and winter.

The immediate charge of the exhibits was placed in the hands of Mr. R. E. Earll, who had in a very satisfactory manner performed similar service at previous expositions.

The space assigned to the Institution for its exhibit was in the southwestern quarter of the Government building, and contained 5,300 feet of floor space, exclusive of the central aisle. The approaches were by two entrances, one to the right of the southern portal and one to the left of the eastern portal of the building. (*See* Pl. LXI.)

Most of the objects, as above stated, were from the collections of the National Museum, and they were so arranged as to enable them to be studied in regular sequence, beginning at the southern portal. They were grouped in alcoves 20 feet in width and from 12 to 20 in depth, on either side of a broad passageway 150 feet in length, as shown in the following diagram, and designated by the letters A, Q.

On the right of the main entrance were a large picture of the Smithsonian building, a portrait of Secretary Langley, and a complete set of the publications of the Institution, about 200 volumes; also photographs of apparatus and illustrations of the work in the Astrophysical Observ-

atory and photographs of the National Zoological Park; a map, 20 feet by 10, showing the geographical distribution of the correspondents of the Institution, 24,000 in number, as entered on the books of the International Exchange Bureau; also one of the fifty sets of Government documents which are sent annually abroad by the Bureau.

In making the arrangement referred to, an attempt was made—

(1) To give as good an idea as possible of the character of the treasures which are preserved in the Museum, by presenting an epitome of its contents, with contributions from every department.

(2) To illustrate the methods by which science controls, classifies, and studies great accumulations of material objects, and uses these as a means for the discovery of truth.

(3) To exhibit the manner in which collections are arranged, labeled, and displayed in a great museum.

(4) To afford as much instruction and pleasure as possible to those who visited the Atlanta Exposition, to impress them with the value of museums as agencies for public enlightenment, and thus to encourage the formation of public museums in the cities of the South.

DEPARTMENT OF MAMMALS.

In the entrance alcoves (A, B) was placed also the contribution of the department of mammals. In a large wall case was a series of 43 specimens to illustrate the range of forms in the class of mammalia, and in a general way the manner in which they are classified by naturalists.

Each of the 11 orders—Primates, Chiroptera, Insectivora, Carnivora, Rodentia, Ungulata, Cetacea, Sirenia, Edentata, Marsupialia, and Monotremata—were represented. There were also five groups mounted in the best style of modern taxidermy, and intended to show, by the use of natural accessories, how the animals appeared in their native haunts. Flanking the arch on one side was a group of Rocky Mountain Sheep or Bighorns (*Ovis canadensis*), 6 in number, from Wyoming, and on the other a group of Rocky Mountain Goats (*Mazama montana*), 3 individuals, collected in British Columbia and Montana, by Mr. George Bird Grinnell. There was also a family group of the Coyote or Prairie Wolf (*Canis latrans*), mounted by Mr. W. T. Hornaday, from specimens obtained in Montana, and one of the finest examples of mammal mounting in existence; also a family group of the Nine-Banded Armadillo (*Tatusia novemcincta*), from Texas, and another of the American Badger (*Taxidea americana*), from Kansas.

TYPES OF MANKIND.

Near the entrance stood a portrait statue of Osceola, the great Seminole chief, who was born on the Chattahoochee River, in Georgia, in 1804, and who led his people in the Florida Indian war, which was ended by his capture and his death in 1838. This figure was modeled by Achille Colin and Theodore Mills from a portrait by George

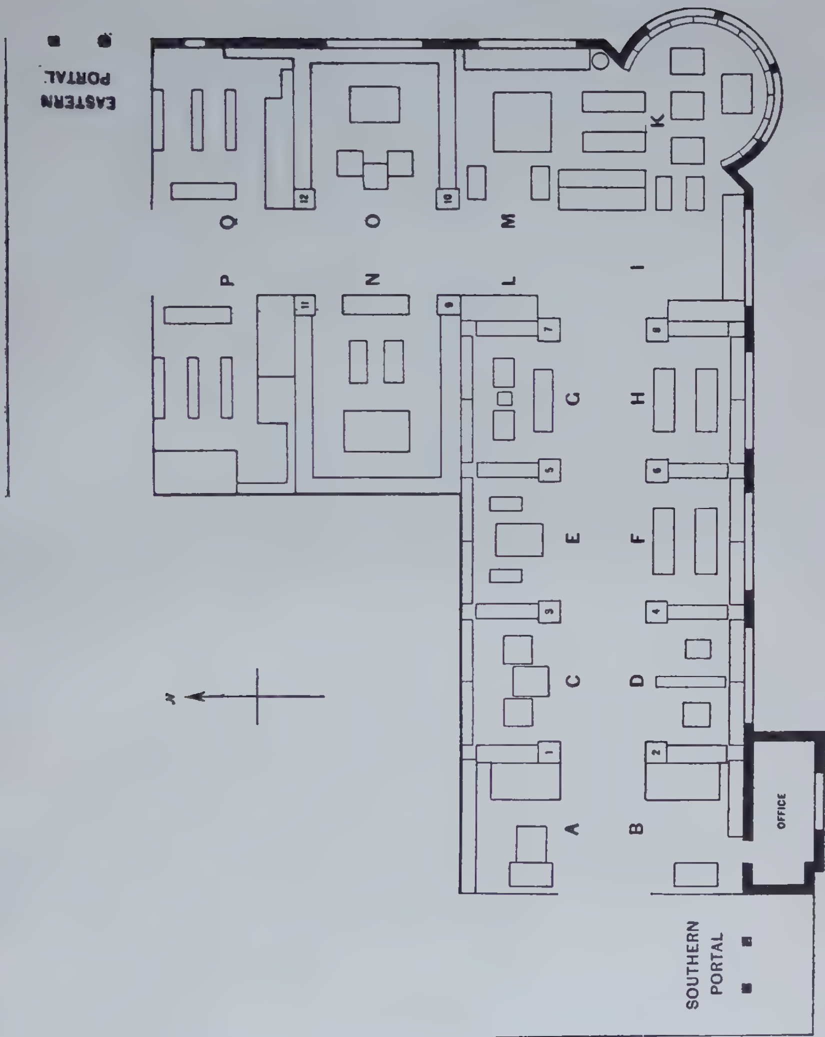


DIAGRAM OF SPACE, SMITHSONIAN INSTITUTION, U. S. GOVERNMENT BUILDING, ATLANTA, 1895.

Catlin, and represents the war chief at the time of his greatest power.

Beyond the archway attention was first attracted by a series of costumed figures, which were arranged on the sides of the main hall at the entrance to the alcoves. These were intended to illustrate the physical characters and the ethnical costumes of twelve of the most characteristics types of the human species. The costumes, most of which were now exhibited for the first time, had been collected by the explorers and correspondents of the institution, and the figures, in sculptor's plaster, have been modeled either from life or from abundant material in the Museum, under the superintendence of Professor Mason and the immediate direction of Dr. Walter Hough. Each of the four divisions of mankind was represented by three figures.

Although dispersed through the entire exhibit, their relation to each other is so intimate that they are here grouped together. Their sequence is indicated by the large numbers above the cases.

BLACK TYPES.

(1) *Papuan*, of New Guinea, modeled by Theodore A. Mills, from photographs in the National Museum.

Costume: A feather plume, earrings, and nose pin, anklets of shell-disks with boar's tusk pendant, armlets and wristlets of shell, and a large waist belt of bark, carved on the exterior.

(2) *Australian*, from the Clarence River district, Australia, modeled by Theodore A. Mills from photographs.

The figure carries a boomerang and wears an apron of kangaroo skin.

(3) *Zulu*, from Southeast Africa, modeled by Henry J. Ellicott, from photographs by Emil Holub.

Costume: An apron of cow tails, assegai held in hand.

BROWN-RED TYPES.

(4) *American Indian*, of the Jivaro stock of Peru, modeled from a life-sized painting, by a Peruvian artist, in National Museum.

Costume (collected by Lieut. W. E. Safford, U. S. N.): Apron of feathers of tropical birds upon a foundation of bark cloth, anklets, etc., of seeds, beetle wings, and teeth of monkey and puma.

The Jivaros live on the head waters of the Maranon and are thought to belong to an independent stock.

The other native stocks of North America are represented more fully in groups elsewhere displayed.

(5) *Dyak*, from Borneo, modeled under the direction of W. T. Hornaday, from photographs made by himself in Borneo.

Costume: A Malay sarong. The weapons are a spear of native manufacture and shield with tufts of human hair and a curious serpentine dagger of the form called the "creese."

(6) *Maori*, of New Zealand, modeled by Henry J. Ellicott, from New Zealand photographs in the National Museum.

Costume: Robe of New Zealand flax (*Phormium tenax*); shoulder cape of feathers; scepter of a chief held in both hands.

The Maoris, at present on the verge of extinction, are among the most perfect types of physical beauty.

YELLOW TYPES.

(7) *Eskimo*, from Hudson Bay, modeled by Theodore A. Mills, from photographs and from life masks in the National Museum.

Costume: Reindeer skin, with gloves of polar-bear skin, collected by New Bedford whalers.

(8) *Tibetan*, from Eastern Tibet, modeled under the direction of W. W. Rockhill, from photographs taken by him in Mongolia.

Costume: A woolen robe and boots of native manufacture.

(9) *Siamese*, modeled by Theodore A. Mills, from photographs obtained by Gen. J. B. Halderman, United States minister to Siam.

Costume: Robes of native fabrics, presented by the King of Siam.

WHITE TYPES.

(10) *Arab sheik*, modeled by Monsieur Hébert (replica of his figure in the Trocadero Museum, Paris).

Costume: Woolen robe or burnoose, turban of camel's hair, with cord, etc., gift of the Trocadero Museum.

(11) *Armenian*, from Erzerum, modeled by Theodore A. Mills, from life.

Costume (collected by Talcott Williams, of Philadelphia): A turban, embroidered coat and trousers, and robe of blue grosgrain silk shot with gold.

(12) *Berber*, from North Morocco, modeled by Theodore A. Mills, from photographs by Talcott Williams.

Costume (collected by Talcott Williams): An inner garment and outer robe called the "haik;" gun of native manufacture.

DEPARTMENT OF BIRDS.

The birds were shown in six cases, five of which contained groups mounted in the midst of accessories, which represented their natural surroundings and are intended to illustrate their habits and characteristics of different ages and sexes. (Alcoves C, D.)

Bower-Birds and their playhouses.—This illustrates the curious habits of the Satin Bower-Birds, of Australia which construct a "run," or bower of twigs, decorated with brightly colored feathers, shells, bleached bones, and other conspicuous objects. They steal buttons and other bright things from the natives, who, it is said, search these bowers for objects which they miss from their homes.

Lyre Birds and their dancing mound.—The Lyre Bird (*Menura superba*) is peculiar to Australia, where it inhabits the densest forests. It has a curious habit of building round hillocks, upon which the male parades with outspread tail while uttering his curious cries.

American Flamingoes and their nests (from a photograph).—This group shows the manner in which the Flamingo sits upon its eggs; the specimens are from the Bahama Islands, where the nests are made of decomposed white coral.

Mexican Jacanas.—These specimens, from Lake Patzcuaro, in Michoacan, Mexico, illustrate the peculiar habit of walking upon floating leaves of aquatic plants, for which these birds are well adapted by their long, slender toes.

The Interrupted Dinner.—This group, mounted by Mr. F. A. Lucas, received a diploma of honor at the Boston exhibition of the Society of American Taxidermists. A Red-Tailed Hawk, while eating a Grouse or Pheasant, is attacked by a marauding Goshawk.

Collective exhibit of Birds of Paradise.—A representative collection, including about thirty different species of this family of birds from New Guinea, so remarkable for the beauty of its plumage.

DEPARTMENT OF REPTILES.

A group of the poisonous snakes of the United States (Alcove E), in connection with which was shown the important illustrated memoir upon "The Poisonous Snakes of North America," by Dr. Leonhard Stejneger, which had just been published by the museum. The specimens had been brought together from widely separated localities. The following species were represented:

(1) Diamond Rattlesnake (*Crotalus adamanteus*), Southwestern States; (2, 3) Banded Rattlesnake (*Crotalus horridus*), Eastern States, south to Florida and the Mexican Gulf, west to Kansas; (4) Prairie Rattlesnake (*Crotalus confluentus*), Great Plains; (5) Western Diamond Rattlesnake (*Crotalus atrox*), Southern United States, from Texas to the Gulf of California; (7, 8) Southern Ground Rattlesnake (*Sistrurus miliarius*), Southeastern States; (9, 10) Copperhead (*Agkistrodon contortrix*), Eastern and Southern States; (11 to 13) Water Moccasin (*Agkistrodon piscivorus*), Southeastern States; (14) Harlequin Snake (*Elaps fulvius*), Southeastern and Gulf States.

DEPARTMENT OF FISHES.

The Department of Fishes shows (Alcove E) a portion of a collection, which, if exhibited as a whole, would have contained a representative of every one of the 250 existing families of fishes. The abridged collection actually shown included 73 of the most characteristic American families. The method of installation was a new one.

DEPARTMENT OF COMPARATIVE ANATOMY.

This collection occupied the wall space in Alcoves C and D, and its exhibits, arranged by Mr. F. A. Lucas, were intended to illustrate the structure of a considerable number of the most interesting types of the animal kingdom.

The collection was arranged in four groups, as follows:

Representative forms of invertebrate animals.—Here were exhibited most of the orders of the invertebrate animals in such a manner as to illustrate their external appearance, general structure, and mode of growth. The smaller and more perishable forms, as well as certain details of anatomy, were illustrated by enlarged models and drawings.

Embryology and development.—Here was shown the early stages of various animals, showing the curious transformations undergone by the Starfish, the Water Beetle, the Lancelet or Amphioxus, the Trout, and the Frog; the development of the domestic fowl and the earlier stages of man. There was also a series of models showing the development of the *Gastrula*, the most important and significant germ form of the animal kingdom, through which all animals above the Protozoa pass in the earliest period of development.

Modification of the skeleton for locomotion.—This series was intended to show how the Fish, Turtle, Penguin, and the Seal, representing four classes of animals, are so modified as to be all equally at home in the water; how the bat can fly like a bird, a frog leap like a kangaroo, and a snake swim, climb, and crawl, although it possesses no limbs at all. The modifications of the skeleton for climbing are illustrated by a Macaque, a Specter-lemur or Tarsier, and a Sloth; modifications for leaping by the Jerboa, Kangaroo, and Frog; for crawling, by a Water Snake; for digging, by the Mole and Gopher; for swimming, by the Fur Seal, the Penguin, the Turtle, and the Golden Mackerel or Crevalle; for sailing, by a Flying Lemur or Colugo, a Phalanger, and the strange little lizard, *Draco volans*, known as the Flying Dragon; for flying, by a Stork and a Bat.

Above the cases are shown the skeletons of a Black Bear, a Tapir, a Manatee, and a Porpoise.

Anatomical models illustrating structure.—These models are on a large scale, and are intended to show organs which are so minute in size or so delicate in structure that they can not otherwise be exhibited. One model illustrates the structure of the Precious Coral, and teaches how the various single polyps are connected with each other and to have a common circulation, so that what is eaten by one benefits all. Others show, upon a large scale, the various organs of complicated anatomy of a large fish, a medusa, a fluke-worm, a marine worm, a bee, a frog, and a perch.

DEPARTMENT OF MARINE INVERTEBRATES.

This exhibit was in part a continuation of that of the Department of Comparative Anatomy, and included, arranged nearly in systematic order, a series of specimens representing the principal groups of marine animals, beginning with the lowest or Protozoa, and embracing at the other extreme the Ascidians and Cephalopods and the Amphioxus or Lancelet, which is by many authorities regarded as the transition between invertebrate and vertebrate animals.

An attempt was made to show the general character of the lower forms of animals which inhabit the ocean. The series began with the Foraminifera, the smallest of the shell-bearing Protozoa, and ends with the forms which are believed to be the nearest to the vertebrate animals. Most of the types shown are familiar only to the professional naturalist, and are not even provided with popular names; no attempt was made, therefore, to describe this series in detail or to do more than mention some of the most familiar types. Sponges were shown, both as they grow and after preparation for use, and among them was the beautiful lace-like "Venus' Flower Basket." There were also sea anemones, corals, and jelly-fishes, among the specimens illustrating the group Coelenterata, etc., some of the most beautiful being from the Naples Zoological Station and the explorations of the Fish Commission off the New England coast. Among the Sea-Worms are the forms known as Sea-Mice, Sea-Centipedes, and Tube-Worms. The group known as Echinodermata was illustrated by specimens from each of its five orders: (1) the Crinoids or "Sea-Lilies;" (2) the Starfishes; (3) the Ophiurans or "Brittle-Stars;" (4) the Echinoids or "Sea-Eggs;" (5) the Holothurians or "Sea-Cucumbers." There were also specimens of the Cephalopod Mollusks, including the Pearly Nautilus, the Octopus or "Devil-Fish," and the Squids and Cuttlefishes.

The series ended with the representative of the so-called Protochordata, which includes the Ascidians or "Sea Squirts," and the Lancelet, which, as has been said, occupies debatable ground, and was also shown in the exhibit of the Department of Fishes.

DEPARTMENT OF MOLLUSKS.

This was shown in Alcove F, and is properly a part of the synoptic series of marine invertebrates. It was exhibited in a single table case, and Mr. C. T. Simpson had made the most of the very small space available in selecting specimens which showed the wonderful beauty and variety of form in the class of Mollusks. The exhibit is described by him as follows:

The families and subfamilies of recent shell-bearing mollusks are arranged essentially according to Tryon's Structural and Systematic Conchology. Nearly all the shell-bearing families are represented.

In the collection Nos. 1 to 4 represent families of the class Cephalopoda, the most highly organized of the mollusks. It includes the Chambered Nautilus, represented by numerous species in past geological ages, but of which only four species are now living; the Argonauts, or Paper Sailors, a genus in which the female only has a shell, or rather an egg case, which is detachable from her body; the Octopuses, Cuttlefishes, Squids, and Ammonites, the last being extinct shells with marvelously complicated chambers.

No. 5 represents the Pteropoda, a class of mollusks having thin, fragile, glassy shells, which float on the surface of the sea. They are sometimes called "Sea Butterflies," and serve as food for whales.

Nos. 8 to 136 represent the class Gasteropoda. Of these, Nos. 66, 67, 70 to 75, and 129 to 132, are families which inhabit fresh water; Nos. 119 to 128 are terrestrial, and the remainder for the most part live in the sea. The shell of the Gasteropods is typically spiral, but varies from a mere flat plate like that concealed under the mantle of *Limax*, through conical, tubular, and coiled forms to the regular spiral. Nearly all spiral shells are dextral (right-handed), but some few families or genera are sinistral (left-handed), as for example the *Achatinellidæ* (No. 118). The Gasteropods include a large number of useful ornamental species. Among those of economic importance are the *Buccinidæ*, the *Littorinidæ*, and the *Trochidæ*, many of which are used for food.

No. 137 represents the class Scaphopoda. The shells of some of this class are used by the Indians for making wampum.

Nos. 138 to 199*a* represent the class Pelecypoda or bivalves. Most of these are marine, but Nos. 179 and 180 live in fresh water. Many are beautiful and valuable, while others are injurious. The wood borers (No. 141) destroy the piling and the planking of vessels and dry docks. Some of the *Mytilidæ* and *Ostreidæ* are edible. The *Aviculidæ* produce pearls and mother-of-pearl.

The class Brachiopoda, which doubtfully belongs with the Mollusca, was extremely abundant in past geological ages, but is now represented by only a few species, most of which inhabit deep seas.

DEPARTMENT OF INSECTS.

This display occupied the wall space in Alcove F, and was of course very far from completeness either as an exhibit of insects or as an illustration of the wealth of material in the entomological collections of the Museum. Here, thanks to the pains of Prof. C. V. Riley, the limited space had been utilized to admirable advantage. The exhibit is described by him as follows:

The chief exhibit, arranged in twenty-four frames, is designed to illustrate the peculiarities of the various families of insects. It is limited to Hexapods, or insects proper, and does not include the Spiders, Mites, and Myriapods, and in fact some of the families of the true insects are necessarily omitted. The object of this family exhibit is a twofold one: First, to give the student the salient characteristics by which he may be able to refer any insect to the family to which it belongs, and also to illustrate what are considered as family characteristics as compared with the larger and lesser groupings or alliances. The second object is to give a very good exhibit of the North American fauna, since by selecting types illustrative of each family the beholder gets a very fair impression of the character of the North American insect fauna, the family illustrations all being drawn from North America.

The second portion of the exhibit is designed to relieve the monotony of a series prepared solely for instruction by adding something pleasing to the eye. Thus eight frames have been arranged as a sort of attractive entrance to the alcove. These consist of beautiful Lepidoptera and Coleoptera which have been purposely chosen from the four

great sections of the globe not represented in the family collection. Thus there are two boxes of European butterflies and moths, one of Asiatic, one of African, three of South American, and one of South American beetles. These "show" cases, for such they practically are, differ, however, from similar show collections in having each insect properly named, so that many a specimen which has perhaps become familiar to the museum or exposition visitor by virtue of its attractiveness and brilliancy will here be properly introduced by name, and thus give an added pleasure to those who wish to be able to call things by name.

DEPARTMENT OF PALEONTOLOGY.

The exhibit occupied one double case in Alcove G, and was intended to show, so far as could be done in a small space, the character of the collections in the Museum and the manner in which they are arranged and labeled. It included one hundred and sixteen species of North American fossils, arranged according to their geological age, and is described as follows by Mr. Charles Schuchert:

The fossils are arranged in the order of their appearance, or chronologically, with a view to illustrate some peculiar characteristic of the geological systems. The surface distribution of each system is shown on the colored map of the United States on top of the case. The oldest undoubted fossil-bearing horizon in North America is the *Cambrian*, which is distinguished for the variety and abundance of its trilobites or lowly organized crustaceans (shown on the extreme left of the case). It is remarkable that so early in the history of life great diversity of structure is attained, since this system has all the essential types of invertebrate animals or organisms without internal hard skeletons, such as Sponges, Corals, Molluscs, and Crustaceans. In the next section—the *Ordovician* system—the Mollusca or shell-bearing animals are present in great diversity of form. These animals continue prominently throughout all succeeding geological formations, and are particularly abundant in the Tertiary strata. The *Devonian* is marked by extensive coral reefs, of which but a few species can be here shown, on account of their large size; at this time peculiar strongly armored fishes also abound. The *Carboniferous* system, more particularly the Lower Carboniferous, is characterized by the development of Crinoids or stone lilies, animals related to starfishes. A number of excellent specimens from the celebrated locality at Crawfordsville, Ind., are shown. This system is also peculiar for the first abundant and diverse development of land plants whose remains have supplied the material for the many coal seams. In the shale bands between the coal or in the roofs of coal mines beautiful ferns abound, some of which are shown.

In the Carboniferous air-breathing animals occur rarely, but in subsequent strata land animals are more numerous. In the Jurassic, or the system immediately below the Cretaceous, great reptile-like animals—the Dinosaurs—abounded, some 70 feet and more in length, continuing to the close of the Cretaceous. Among shelled animals the Ammonites are particularly peculiar to these systems.

From the Tertiary formations of the Rocky Mountain region their young have been exhumed, many and diverse mammals or animals that

suckle. These are the ancestors of many modern land animals now inhabiting land areas other than North America. Among them were very small horses with three toes on each foot, camels, tapirs, elephants, etc. One of the characteristic sea animals of this time abounding in the Gulf border region is the Zeuglodon Whale, a form related to both whales and seals. A restoration of the skeleton of this long and slender animal is shown suspended from the roof. The shelled animals of this era at once remind us of living species.

This collection also aims to show methods of displaying fossils now in use in the Department of Paleontology. The fossils are cleaned of all adhering rock, and when possible a series of each species is selected to show specific varieties, being then glued upon encaustic tiles. The advantage of tiles lies in the fact that they will neither fade nor warp, are more uniform in size, and nearly as cheap as paper, or thin wooden tablets. In cases where the attached specimens must be removed, this can readily be accomplished by soaking in water without injury to the tiles.

DEPARTMENT OF GEOLOGY.

In a single case in Alcove H was a collection illustrating the occurrence and association of gold and silver in nature, which is thus described by Prof. George P. Merrill:

The exhibit begins with a series of specimens showing both the native metals and their compounds in the condition of greatest natural purity. This is followed by a series of the same compounds with their characteristic associations, but in which the metal-bearing portions are still plainly evident, and this in turn by a third series showing selected types of the ores as mined, but in which, as a rule, the metal or its compounds are scarcely discernible.

Attention is called to the fact that while gold, aside from its native form, enters as an essential constituent into less than half a dozen known minerals, silver occurs in upward of six times as many. Thus gold, aside from its natural alloys with silver (electrum), bismuth, and palladium, is found in chemical combination with other elements only in the minerals petzite, sylvanite, krennerite, and nagyagite. Silver, on the other hand, is found native, as an alloy with gold (electrum), or mercury (amalgam), and also as an essential element in compounds forming nearly forty mineral species more or less well defined.

Several of these compounds are very rare, and not at present included in the series exhibited.

It is further to be noted, that while both gold and silver occur either as native or in compounds of such size as to be easily seen by the naked eye, the great majority of ores of either metal are composed in large part of other substances with which the metal is so finely and intimately admixed as to be invisible and determinable only by chemical means or where it occurs as a replacing constituent with other elements. Thus the most common form of gold ore is an auriferous pyrite, while the most common silver ore is an argentiferous galena.

In the series as exhibited attention needs to be called, first to the native gold, that is, the gold found in the metallic state in nature as displayed in the form of nuggets, leaf gold, wire gold, and gold dust

from various localities; second, to the compounds of gold with silver, tellurium, antimony, and sulphur as shown in the minerals petzite, sylvanite, krennerite, and nagyagite; third, to the occurrence of the native metal with its associates, either as dust or nuggets in sand and gravel, or impregnating quartz, slate, calcite, and other minerals forming the characteristic gangue, and lastly to the series of gold ores, representing the metal-bearing rocks as usually mined, and which, while, as above noted, showing no trace on casual inspection of the precious metal, nevertheless contain it in sufficient amount to render its extraction by chemical or mechanical means a profitable industry.

The silver-bearing series is arranged in a similar manner. It is to be noted that while gold is common in deposits of sand and gravel, as "placer gold," silver very rarely occurs in this form, and is represented here only by the silver-bearing sandstone from Washington County, Utah. Native silver in the form of "wire" or "moss" silver is, however, comparatively common, as shown in the specimens from Mexico and Saxony. Some of the silver-bearing compounds are of great beauty, as illustrated in the ruby silvers, proustite and pyrargyrite.

The total annual production of gold and silver for the world for 1894 is given as 8,616,892 ounces of gold, and 166,437,408 ounces of silver.

DEPARTMENT OF MINERALS.

This department (Alcove G), was represented by a collection of high educational importance, arranged by Mr. Wirt Tassin, under the direction of Prof. F. W. Clarke, the curator, and is described as follows:

Entering the alcove the wall cases contain a series of minerals selected and labeled to illustrate the several properties or characters of one mineral species as compared with other mineral species, in other words, "comparative mineralogy."

The first case on the left contains a series of 143 minerals illustrating chemical mineralogy; that is, the composition, variation in composition, and the relation of composition to form of minerals.

The chemical composition of minerals is illustrated by several typical elements together with a majority of their combinations. It will be observed that gold has comparatively few combinations, and that its occurrence is practically restricted to the element; while iron, the most useful of the heavy metals, rarely occurs as the element, yet affords a great number and variety of compounds.

Proceeding from left to right, the next case contains a series of models and specimens illustrating the principal forms of minerals depending upon molecular structure of form.

Beginning with the system of crystallization each system is represented by a typical crystal group followed by models and specimens showing the principal forms belonging to that system.

For example, fluorite, a typical isometric mineral, is shown, then a glass model of the fundamental isometric form, the octahedron, and spinel; a typical octahedral mineral. Following the system of crystallization are crystal aggregates, including twin crystals, parallel growths, and imperfections of crystals.

The next wall cases contain series illustrating isomorphism, pseudomorphism, and the various characters depending upon the action of the several physical forces, such as light, cohesion, mass, heat, etc.

The floor case on the left contains several minerals, arranged to show the great diversity and beauty of their coloring.

The floor case on the right contains meteorites showing the general character and composition of those bodies. Attention is called to the large meteorite on the pedestal, weighing 746 pounds from Canyon Diablo, Arizona, and to the several other meteoric irons in the case, from the same locality. These irons are of interest because of the great size and extent of the "fall," over 10 tons of them having been found in the region, and also from the fact that they contain microscopic diamonds.

SYNOPSIS OF ARRANGEMENT.—COMPARATIVE SERIES.

I. *Chemical mineralogy.*—Chemical composition; variation in composition; relation of composition to form.

II. *Physical mineralogy.*—Crystallography; compound crystals; isomorphism, Pleomorphism.

Pseudomorphs.—Characters depending upon light: luster, color, diaphaneity; characters depending upon cohesion: cleavage, fracture, tenacity, hardness; characters depending upon mass: heat, magnetism, and electricity; specific gravity: fusibility, magnetism, and electricity.

DEPARTMENT OF BOTANY.

This exhibit occupied three sides of Alcove II, and consisted of a collection of the woods and shrubs of Japan mounted in a very original and beautiful manner by Japanese artists. To each species was devoted a polished panel, made of its own wood, upon which were painted the leaves, flowers and fruit, while the panel was framed with its own bark.

The collections belonging to this department are, for the most part, not available for exhibition purposes, being chiefly dried specimens for research work. The national herbarium contains a quarter of a million mounted plants.

DEPARTMENT OF MATERIA MEDICA.

The exhibit of this department, Alcove II, consisted of a case illustrating the composition of a number of the principal mineral waters used as beverages and for medicine. By the side of a bottle of the water, as found in commerce, are placed a number of smaller bottles, which contain the amount of each chemical substance found in the amount of water shown in the first bottle. Here, also, is a case which illustrates the composition of the human body by displaying in bottles the exact quantity of each substance to be found in the body of a man of average size (154 pounds), while in a parallel series are shown the quantities of each element in the same man's body.

DEPARTMENT OF PREHISTORIC ANTHROPOLOGY.

This exhibit occupied Alcove I, and consisted of a small, carefully selected collection of implements and objects used by man in prehistoric times, the specimens being mostly American.

The explanation of the exhibit is contributed by Dr. Thomas Wilson:

In this exhibit 792 specimens are displayed, as follows: Stone, 410; copper, 110; shell, 26; bronze, 78; gold, 26; bone, 18; pottery, 124.

Anthropology is the science of man considered in all of his parts and nature. Prehistoric anthropology is that part of this great science which relates to man in prehistoric times. "Prehistoric" means before written history was begun in the locality or country under consideration. History began several thousand years earlier in Egypt and the classic Orient than in Gaul and Britain, and these fifteen hundred years earlier than America. Knowledge of the existence of prehistoric races began with the discovery, about the year 1806, of the ages of Stone, Bronze, and Iron in the Scandinavian countries. It was not recognized in its full scope until the discovery in France, about 1859, of what is called the "Chipped Stone" or "Paleolithic" Age. Since, the antiquity of man has been a subject of lively discussion in most countries, and many attempts have been made to construct the history of his early times. The announcement by Darwin of his theory of "Evolution" as the origin of the human species added interest to the investigation. The study of the life, customs, culture, and, indeed, the making of the history of prehistoric man can only be done through the investigation of objects made and used by him. This investigation considers their condition, the mode of their manufacture, their associations, and the places wherein they have been buried, with the incomplete information we get from the skeletons. In its relation to the North American Indian we are dependent upon the objects we find in his workshops, his destroyed homes, or in his graves and monuments. We study his mounds and earthworks, cemeteries, village sites, quarries, and workshops. We find his axes, hatchets, adzes, and gouges, and from these we speculate how he felled trees, cut wood, and made boats, sledges, and the hundred objects of wood employed by savages. His stone quarries and workshops show the raw material, and how he manufactured his implements by the processes of chipping, grinding, polishing, and drilling. The same for horn, shell, and bone, of which we possess many thousand objects made into beads, pins, gorgets, and other ornaments. The copper and gold objects are to be studied on the same lines. Pottery was much used by prehistoric man, and its manufacture was carried on wherever he dwelt. The pottery exhibit is displayed on the shelves above the flat-topped cases. To the right are specimens of European prehistoric pottery of the Neolithic and Bronze ages. This is followed by ware from the aborigines of the United States. The long shelves in front contain specimens from Mexico, Central and South America. On a pedestal is a reproduction of an "Ogham stone," illustrating a rude written language which was prevalent in Ireland at a very early day.

THE ORIGIN AND SIGNIFICANCE OF GAMES.

In the next alcove (K), which occupied the circular tower in the southeast corner of the building, is displayed a special collection illustrating "The origin and significance of games in all parts of the world," especial prominence being given to chess and cards. The display was made in cooperation with the University of Pennsylvania, and has been arranged by Mr. Stewart Culin, director of the University Museum.

The objects, arranged in a progressive series, fill 34 upright cases, like pictures in frames, and one large table case. They form an almost

complete history of cards and chess, beginning with the primitive forms originally used for divination, down to the games of the present day.

Especial interest attaches to the fact that the clue to the origin of both chess and cards was found by Mr. Culin, with the aid given by Mr. Cushing, among the aboriginal people of America. The pack of cards is shown to have originally consisted of a bundle of arrows, marked with the signs of the world quarters. The shaftments, or feathered part of these arrows, bearing cosmical marks, were first used in fortune-telling, and from their use our card games arose.

In America the Indian did not get beyond the use of carved and painted staves. The American case shows arrows of the McCloud River Indians, of California, marked with colored ribbons, by which they were distinguished. Side by side with them are the gambling sticks of the Haides, of Vancouver Island, similarly marked with rings of color and used like cards in their gambling even at the present day. In the adjoining case, devoted to Eastern Asia, the practice arrows of Korea are shown, and with them the derived playing cards here made of oiled paper, yet bearing both on their backs and faces devices copied from the cut feathers of the arrows. With them are Chinese cards with the same emblems surviving as markers or indexes at the ends. These cards are "double-headers," as indeed were the gambling sticks, carrying back the idea of our common playing cards with double heads and index marks to the most remote antiquity. The Japanese cards, in the same case, bear emblems derived in part from the same source, while the circular cards, called Gunify, of which a beautiful pack is shown, are painted in colors to correspond with the world quarters. A single pack of the national cards of each of the principal countries in the world follow, comprising, in Europe, Germany, France, Spain, Italy, Switzerland, Austria, Sweden, England, and Russia. The card series closes with the pack with pictures of the Chicago Exposition and the cards with pictures of the Confederate flag, made in England for sale in the South during the war.

The chess series begins, like that of cards, with the divinatory games of primitive people, in which our game originated. America is here again conspicuous, and, with the objects representing the first steps in the evolution of the game, are shown other common things, such as visiting cards and the folding fan, which Mr. Culin traces, with chess, to the marked arrow of primitive culture. The historical chess series comprises boards and men from India, Burmah, the Malay Peninsula, the Maldive Islands, Korea, China, and Japan.

The specimens are all arranged as in actual play.

DEPARTMENT OF ARTS AND INDUSTRIES.

In Alcove K was shown also a small case containing a collection of ancient glass from excavations in the vicinity of Tyre and Sidon, remarkable not only for its beauty of form but on account of the entirely iridescent coloring which it has acquired through having been buried in the soil for twenty centuries or more.

Adjoining this was a case of carved ivories from Japan. The native sculptors have shown, with great minuteness and accuracy, the costume, tools, and methods of work of a large number of the native mechanics before the introduction of any European implements—the carpenter, the mason, the armor maker, the lantern maker, the umbrella maker, the cooper, etc.

Here also was shown a collection to illustrate the development of the ceramic art in Japan. This had been arranged by Mr. Heromich Shugio, and, although it did not contain any considerable numbei of very costly pieces, it was historically quite complete, and was described by Mr. Shugio as follows:

Japanese history mentions that some pottery was made in a village of Idsumi to a considerable extent from the very early days, and that another factory was in existence in the province of Ouri during the period of 581–660, B. C. Twenty-nine years before the Christian era Tenno Suijin ordered that human figures made of burnt clay be buried with his wife, Empress Hihasubrine, in place of her attendants, as had been customary until that time whenever any member of the imperial family died. This humane decree abolished an abominable custom, and the pottery in its infancy played one of the most important and noblest acts in history.

The early productions were of more unglazed burnt clay, not like those of the early American pottery.

The introduction of the potter's wheel by Giyoki, a priest of Idsumi, in 724 A. D., must be taken as the real beginning of our ceramic art.

The first glazed stoneware is said to have been made by Kato Shiroye, now at Seto, in the province of Owari, in 1223 A. D., after his return from China, where he spent several years in studying ceramic art. From his time, Seto became the center of ceramic art, and all the ceramic productions came to be called "Seto mono" in Japan, as all the porcelains are called "China" in Great Britain and America.

The first porcelain was made by Gordayu Shonsui, a native of the province of Ise, who studied ceramic art in China in about 1513. His productions were mostly made with Chinese materials, which were brought back by him from that country, and they were decorated in blue under the glaze.

The greatest progress in Japanese ceramic art has been made since the triumphant return of the Korean expedition in 1859, when many skillful Korean potters were brought over and the famous ceramic factories of Hizen, Higo, Chikuzen, Satsuma, Tosa, Nagato, Yamashiro, Owari, etc., were either established or improved by those potters.

The first potter who succeeded in decorating porcelain with enamel paintings over the glaze was the celebrated potter Kakiyemon, of the Sakaida family of Nangawara, a village near Arita, who mastered this secret of enamel painting from Tokuzayemon, of Imri, who learned his method from a captain of a Chinese ship at Nagasaki in 1640.

Kakiyemon was assisted in his essays in enamel painting by Gosu Gombei, another well-known potter. In 1646 Kakiyemon is said to have sold his decorated porcelains to a Chinese trader in Nagasaki, and thus he has the honor of being the first Japanese potter who decorated porcelains with enamels and who sold Japanese porcelains to a foreigner. Since then his productions were bought by Chinese and Dutch traders at Nagasaki to export. He was honored by Prince Naheshinia Samio, of Hizen, by being appointed a special maker to his highness. Specimens numbers 150 and 151 are his works. Although they are not his best works, they will be found, on close examination, to be the works of a master hand.

Nisei, the great Kioto potter, through the generosity and liberality of Wankiu, a wealthy Osaka merchant, succeeded during 1655–1657 in decorating pottery with enamel painting after the newly introduced method by Kakiyemon, now so much admired as the Ninsei ware.

Number 53 in this collection is a specimen of this great potter, and numbers 54, 55, 56, and 57 are copies after his works. Numbers 56 and 57 were copied by Okumura Shozan, of Kioto, who is, perhaps, the best copist of Ninsei since his time, and some of his copies are often mistaken for the originals, even by Japanese connoisseurs.

Another important epoch in our ceramic art was the discovery of the use of saggers in baking porcelains by Tsuji Kizayemon, a noted potter of Arita, during the Kwhmbum period (1661–1672). The porcelains baked in saggers are called "gokuskin yaki." Number 152 is a specimen of this gokuskin yaki made by one of his descendants, who were honored by being appointed makers to the imperial court of Kioto. The porcelain was and is made at Arita, Okawachi (where Naheshima ware was made), Mikawachi (where Jirado ware was made), Shiraishi, Kameyama, etc., in the province of Hixen; at Seto, in Owari; at Tajimi, in Mino; at Kutani, in Haga; at Kiyomidsu, in Yamashiro; at Sanda, in Settsu; at Himeji, in Harima; at Hikone or Koto, in Omi; at Ota and Tokio, in Musashi; at Okayama, in Kii; Wakamatusu, in Iwashiro, etc., of which nearly all the factories are represented in the collection. Of the important factories where the pottery (faience and stoneware) was and is made this collection represents Satsuma, Karatsu, in Hizen; Takatori, in Chikuzen; Yatsushsro, in Hogo; Shiga, on the island Tsushima; Hagi or Matsumoto, in Nagato; Suwo; Shido, in Samuki; Kosohe, in Settsa; Akahada, in Yamato; Kioto, in Yamashiro; Shigaraki, in Omi; Seti, in Owari; Tachikui and Sasayama, in Tamba; Fujiria, in Idsumo; Iga, Sado, Kutani, in Kaga; Soma, in Iwaki; Imbe, in Bizen; Mianto, in Idsumi; Banko, in Ise, etc.

The collection is displayed in three cases in Alcove K, by provinces, in accordance with the following plan:

Hizen	Karatsu.	Idzumo	Idzumo.
	Arita.	Idsumi	Idsumi.
	Hirada.	Yamato	Akahada.
	Nangawara.	Survo	Survo.
	Nabeshima.	Nagato	Hagi.
	Kakiyemon.	Chikuzen	Takatovi.
	Tsryi Gokushin.	Higo	Yatsushiro.
	Kameyama.	Satsuma	Satsuma.
	Bogasaki.	Settsu	Sanda.
	Shiraishi.		Kirko.
Taishiu (island of Tsushima)	Tsushima.		Kosube.
Owari	Seto.	Iwaki	Soma.
	Horaku.	Kaga	Kutani.
Bizen	Bizen.	Ise	Banko.
Omi	Shigaraki.	Sado	Sado.
	Koto.	Sanuki	Shido.
Kii	Zuishi.	Yamashiro	Raku.
Iga	Iga.		Kioto.
Tamba	Tamba.	Musashi	Tokio.
			Ota.

Across the aisle (Alcove L) was a small series of musical instruments intended to illustrate the character and method of arrangement of the very extensive collection in the National Museum. A series of five times the extent had been selected to be sent to Atlanta, but the limitations of space were such as to make it necessary to reduce this, as well as every other exhibit.

The collection is intended to illustrate a few of the stages in the progressive evolution of stringed instruments. The series begins with a rude musical bow of Mashonaland, which is only used to mark time

and is audible only to the performer, who holds one end between his teeth. At the other end of the series are the guitar and violin; the former represented not only by the well-known European instruments, but by related forms from India and Africa. Intermediate stages are shown by a number of interesting types, named and described upon the labels. The series selected for Atlanta contains about two hundred instruments. The small portion of it shown gives but a meager idea of the great collection in the National Museum, which includes some three thousand forms.

DEPARTMENT OF ORIENTAL ANTIQUITIES AND RELIGIOUS CEREMONIAL.

Alcove M was devoted to a collection of objects illustrative of the Bible, arranged under the direction of Dr. Cyrus Adler, custodian of the collection of religious ceremonials in the Museum. An attempt has been made to show representative specimens of most of the classes of objects which are of value to the students of the Bible, and the collection, though necessarily limited through lack of space, may fairly be said to have constituted a miniature Biblical museum.

The archæology of the Bible is represented by a collection of casts illustrating the ancient Hittites, frequently mentioned in the Bible from the time of Abraham down; by an Egyptian mummy secured by the late Hon. S. S. Cox, United States Minister to Turkey; busts of Rameses II, supposed to have been the Pharaoh of the exodus, and of his father, Seti. Assyria and Babylonia are represented by a model of a temple tower of Babylon, especially constructed for this Exposition. This temple tower was situated in the outskirts of the city of Babylon. The model is made after the description of Herodotus and the report on the ruins discovered by Sir Henry Rawlinson. There is also a cast of a huge Assyrian winged lion, 11 feet long and 11 feet high, such as were placed to guard the doorway of Assyrian temples; cast of the Chaldean account of the flood, etc. Palestinean archæology is represented by casts of Moabite stone, Siloam inscription, and Temple stone.

The ancient religion of the Jews is represented by a case containing a selection of the more important objects of Jewish ceremonial. Still another case shows a collection of the gems of Palestine, with a model illustrating the method in which the gems were placed in the high priest's breastplate. There is also a collection of coins struck in Palestine, as well as those which appeared in Bible times in cities mentioned in the Bible. In another case is a collection of musical instruments of Palestine and adjacent countries, which differ in no wise from those used in ancient times. To these are added a few representations of musical instruments from Egyptian and Assyrian monuments. A collection of domestic implements, such as are mentioned in the Bible, and a relief map of Palestine are also shown.

In this connection is also exhibited a collection to illustrate the history of the Bible as a book and to show the important translations

which have been made of it. The Hebrew Bible is represented by portions of an Egyptian manuscript of the fourteenth century, facsimile of the Aleppo Codex, by the first American edition of the Hebrew Bible printed at Philadelphia in 1810; by other well-known prints in Amsterdam, Antwerp, and Hamburg. The Septuagint or Greek version is represented by facsimiles of the famous Alexandrian and Vatican codices. Following these are copies of the Targum or Aramean version, the Syriac version, the Coptic version (represented by a manuscript), the Ethiopic version, Gothic version, Anglo-Saxon version, the edition of the Latin version or vulgate of St. Jerome, a Spanish-Jewish version, the Arabic version (represented by a manuscript), and the translation of Saadia.

The New Testament is represented in the Vatican and Alexandrian codices, already mentioned, as well as in the Sinaitic and by the first American edition printed at Worcester in 1800.

Finally, there is a most interesting and valuable work, consisting of a New Testament arranged in historical order by clippings from the Latin, Greek, French, and English Testaments, all arranged by Thomas Jefferson. This book contains a concordance of the verses used and a number of notes scattered throughout, all in Jefferson's handwriting, and is said to have been arranged by him for translation into the Indian languages, so that the Gospels might be presented to the Indians in a simple form.

DEPARTMENT OF TECHNOLOGY.

Alcove N was occupied by objects designed to show the more important stages of improvement through which the appliances now in use for the conveyance of men and goods from place to place have passed before the present high standards of mechanical efficiency were attained. These were selected with the special purpose of illustrating the important influence exercised by the South Atlantic States upon the early history of internal improvement in America and the inauguration of trans-Atlantic commerce by steam. The theory upon which they are arranged is thus described by Mr. J. E. Watkins:

The origin of many of the contrivances now utilized by man to facilitate individual movement or to transport objects too heavy to be carried by man belongs to a period so remote in prehistoric time that no attempt to arrange aboriginal water or land vehicles in a definite chronological sequence has been made.

Boats and ships.—Primitive boats, such as the catamaran and dugout canoe, are placed at the beginning of the series, which contains among the craft propelled by poles or oars the Ohio River flatboat and keel boat, by the instrumentality of which the settlement of the Southern and Western States was promoted during Colonial and Revolutionary times. Among the sail ships are to be found the *Sally Constant*, from which the first English settlers in the United States landed at Jamestown, Va., in 1609, and the *Mayflower*, which brought the Puritans to Plymouth Rock eleven years later.

The American steamboat.—The fine rivers of America stimulated the

exertions of several ingenious men living on the Atlantic seaboard to adapt the steam engine to navigation. Prominent among these pioneers, whose labors make good America's claim to the birthplace of the steamboat, was James Rumsey, some of whose experiments upon the Potomac River were witnessed by General Washington as early as 1787. A model of Rumsey's steamboat of 1788 and of that made by Fitch about the same time are shown, together with the model of the first screw-propelled steamboat to navigate the waters of any country, built by John Stevens in 1804. Fulton's *Clermont* of 1807 and Stevens' *Phœnix* of 1808 are also in the series which contains a model of the steamship *Savannah*, built in 1818 by Georgia capitalists, which has the distinction of being the first steamship to cross the ocean, sailing from Savannah, Ga., for Liverpool on her initial voyage Saturday, May 22, 1819. The original log book containing the account of this historical voyage is deposited in the National Museum.

The collection further embraces the following series:

1. Boats pushed by poles or propelled by paddles or oars.
2. Sailboats (driven entirely by the wind).
3. Steamboats.

The American railway.—As the South Atlantic States were foremost in the introduction of trans-Atlantic steam navigation, so were they early in the field of railroad construction. The first railway line 100 miles long built and operated in the world was the railroad, 139 miles long, built by the South Carolina Railroad Company from Augusta, Ga., to Charleston, S. C.; and the first steam locomotive built upon the Western Continent for actual service was the *Best Friend*, which was built for that road in 1830, and went into service in the following year.

Various forms of locomotives experimented with in England and America previous to the construction of the *Best Friend* are illustrated.

The first steam railway train in the South Atlantic States.—The South Carolina Railway was built upon plans which would now entitle it to be called an elevated railway. A model showing the method of track construction, upon which is placed the first steam train that ran in the South Atlantic States, December 14, 1830. Near it are placed models of sleeping-car appliances built for railways terminating at Richmond and Petersburg, Va., the earliest forms of sleeping berths used in American cars.

Land vehicles.—For the purpose of this Exposition the land vehicles are arranged under the following classifications:

I. Land vehicles drawn by men or domestic animals.
   1. The rolling load.
   2. Sledges and rollers.
   3. Vehicles with solid (or nearly solid) wheels.
   4. Vehicles with wheels containing spokes.

II. Land vehicles propelled by natural or generated forces.
   1. Experimental sail cars and horse-power locomotives.
   2. Experimental steam locomotives.
   3. Experimental electrical locomotives.

Early electrical apparatus.—In no other department of science have American investigators, from the very beginning, been so successful, not only in the discovery of fundamental truths, but also in the prompt application of the principles deduced therefrom to useful purposes, as in the domain of electricity.

The success of Franklin's experiments in the year 1784 in the construction of what he calls the "electrical wheel" is illustrated, for the first time, in these collections in the models of the two devices involving

the most important principles utilized in the modern motor, as described by Franklin in his letter to Peter Collinston, London, dated that year, and published on page 252 of his autobiography. Strangely enough no prominence has been given to these ancient electrical machines in subsequent scientific writings relating to the history of electricity.

In the models and photographs of the apparatus designed in 1829 by Joseph Henry, the first secretary of the Smithsonian Institution, are found the instruments by which the electro-magnet was for the first time utilized to convey a signal to a distance. In it is embodied the principle upon which the modern electrical telegraph is based. The first instrument to make a permanent record of words transmitted over a wire by the agency of electro-magnet was designed and constructed by Samuel F. B. Morse in 1837. A model—an exact reproduction of the original machine, too precious to risk removal—which is now in the custody of the Western Union Telegraph Company, has been obtained through the courtesy of the president of that company.

Actively associated with Morse from the date of his earlier experiments was Alfred Vail, a man of great ingenuity and rare mechanical ability.

The original telegraphic instrument by which the historic message, "What hath God wrought?" was received at Baltimore May 24, 1844, and constructed under the direction of Vail. It is one of the valuable treasures deposited in the United States National Museum, the removal of which being prohibited on the ground of safety, is illustrated by a model of full size.

Limitations of space, unfortunately, prevent a more extended exhibit of apparatus connected with the origin of the telephone, the dynamo, and the application of the electrical current for producing light and the transmission of power.

Following is a brief outline of the apparatus exhibited:

III. Early electrical apparatus (models only exhibited).

1. Apparatus designed by Benjamin Franklin.
2. Apparatus designed by Joseph Henry.
3. Telegraphic apparatus invented by Morse and Vail.

In the same alcove were shown the contributions of the Department of History and Numismatics. These consisted of a series of coins and medals, as follows:

(*a*) Principal coins occurring in the North American Colonies from 1525 to the establishment of the United States Mint, in 1793.

(*b*) Medals commemorative of the Revolutionary war.

Among the most interesting coins are the "oak tree" shillings, 1652, and the "Mark Newby" penny, the "rosa Americana" penny, the Continental dollar, of the coins issued by the Colonies before the Revolution. Here also are shown three colored sketches of birds by John J. Audobon, the most famous painter of birds who ever lived, who was born near New Orleans in 1781.

BUREAU OF AMERICAN ETHNOLOGY.

The exhibit of the Bureau of American Ethnology occupied Alcove O, was prepared under the direction of Prof. W. J. McGee, who describes it as follows:

This exhibit illustrates three representative Indian tribes of North America, viz, Cherokee, Papago, and Seri. The Cherokee Indians represent a large and important Iroquoian family or stock; the Papago

tribe forms the leading branch of the Piman stock; while the Seri Indians are the sole representatives of their family. It has been thought better to make moderately full exhibits of a limited number of tribes than to illustrate a large number of tribes incompletely. The Cherokee tribe was selected for representation because of its local interest; the others because they were little known and the collections are quite knew.

The Cherokee Indians were the aboriginal owners of the pine-clad hills and fertile valleys of what is now northern Georgia, the western Carolinas, eastern Tennessee, and a part of Virginia. They were the first occupants of the site of Atlanta. They lingered long in their old hunting grounds, and while most of the tribes have disappeared from the woodlands and mountains, a few remain in the Eastern Cherokee reservation in Swain County, N. C., within 150 miles of Atlanta. The collections illustrating the Cherokee Indians comprises pottery and basketry, largely of primitive types—the aboriginal bow and arrow, with the singular blowgun, which attracted much interest among the earliest white explorers; the eagle-feathered masks and tortoise-shell rattles, and other paraphernalia of the primitive ceremonials; stone implements and pipes, pottery-making tools and domestic utensils, articles of costume and personal adornment, fishing spears, etc. The collection was made within a few years by an expert familiar with Indians' customs, who was enabled to obtain the most ancient and sacred, as well as the modern, possessions of the Indians. While many of the articles are accultural (or affected by the influence of the higher race), many illustrate fairly the aboriginal ideas of the Indians of southeastern United States. The collection fills one wall case, with the larger articles arranged above it.

The Papago Indians are a tribe of the desert. They occupy the hot and dry Papagueria (the most arid region of equal extent in North America), lying south of the Gila River and west of the Sierra Madre Mountains in Arizona and Sonora (Mexico). Their mode of life is the blending of the nomadic and agricultural. They establish settlements by springs and water holes, and, while the ground is moist from one of the rare storms, they plant maize, melons, and beans, which quickly mature; and when the spring fails, or the water hole dries up, the rancheria is abandoned, and the people scatter in search of other sources of water. In autumn they collect the fruits of different species of cactus, mesquite beans, etc., and in winter they migrate to the mountains of Mexico, where they live by hunting. Although discovered and highly esteemed by the early Spanish explorers and missionaries, the Papago Indians are little known outside of their own territory. The collection exhibited is the first one of note, both as to articles and photographs, ever brought to eastern United States. It embraces pottery and water-tight basketry, in the making of which these Indians excel; the crude plow, akin to that of ancient Egypt, and the still more primitive spade or digging stick; games of divination and diversion; musical instruments; bows and arrows, which are still in limited use, with some of the stone implements used by ancestral tribes in the same region; rope-making material and apparatus; domestic utensils, costumes, and the like. The collection is arranged in three wall cases, one of which is allotted to the peculiar articles made chiefly of the agave. These include the mat used for bedding, basketry, the cradle, etc. In addition there is a large floor case showing life-size models of Papago women engaged in pottery making, with examples of the pottery made by the tribe; and the peculiar carrying basket and costumes

introduced were those found in actual use among the Indians last autumn. Many of the articles are accultural, since the Papago Indians have borrowed from the white men such arts as seemed good in their sight; but a part (including the pottery and basketry) are primitive, and some represent perfectly the aboriginal condition of the tribe, among these being the family and other fetiches still in constant use among the Papago Indians. Two additional floor cases contain models of the Papago habitations, which are commonly built of a peculiar grass over a framework of mesquite poles, more rarely of adobe.

The Seri Indians occupy Tiburon Island, in the Gulf of California, and a considerable area of the adjacent mainland of Sonora, Mexico. They are probably the most primitive Indians remaining in North America. They are without agriculture, and have no domestic animals except dogs. Their food is fish and waterfowl from the sea, and game from the land, commonly eaten raw, with the fruits of cacti, mesquite beans, berries, acorns, etc., in season. They have been at war with the neighboring tribes and with whites for three and a half centuries, and lose no opportunity to rob by night, or to murder by ambush or strategy. By reason of their warlike and treacherous character the Seri Indians are little known to ethnologists. The articles and photographs exhibited are believed to be the first ever obtained among them. The collection comprises the bow and arrow (the latter, according to the testimony of Mexicans and Indians themselves, being poisoned), robes of pelican skin which take the place of blankets, face-painting material and utensils, basketry, and their peculiar pottery, as well as their exceedingly meager series of implements and utensils; the collection being complete except for the rude water craft and fishing nets, which it was found impracticable to obtain. The exhibit occupies two wall cases, with a number of articles arranged above them. It includes also a floor case containing a life-size model of a Seri hunter, armed with bow and quiver with arrows. The Seri Indians are notable for tall stature, robustness of chest, slenderness of arms and legs, and dark color of the skin. They are remarkably fleet of foot.

The exhibit includes twelve transparencies (photographs on glass), six representing the Papago Indians with their houses, occupations, costumes, etc., while six represent the Seri Indians with the flimsy wickiups used on the mainland. Their seaside houses, consisting of turtle shell elevated on rocks or poles, have never been photographed.

DEPARTMENT OF ETHNOLOGY.

At the north end of the long aisle (Alcoves P and Q) and adjoining the eastern portal was the exhibit of the Department of Ethnology. This space is adjacent to the eastern entrance, and is actually one of the entrances to the Smithsonian space. On either side of the archway were shown groups of Indian figures, clothed in their native costumes, and engaged in their customary occupations. Especially conspicuous was the Sioux chieftain, in full war paint, mounted on his gaily housed pony, and with feather headdress sweeping to the ground, while facing him was a group of Kiowa Indians engaged in moving their habitation, some mounted upon a horse, and other carried behind it by means of primitive appliances known as the "travois." Beneath there was a group of Kiowa children, another of Navajo women weaving blankets,

also a Crow warrior painting his blanket, and a Chippeway writing an inscription on a tablet of birch bark. Another very striking group of seven figures represented a religious ceremony practiced by the Indians of Prince Rupert's Sound. The principal figure is an Indian who is personating a cannibal, and who is about to leap into the house through a circular door. Two men are holding him back, while four musicians in front are playing upon their rude instruments. The remainder of this space is occupied by an exhibit prepared at the express desire of the ladies in charge of the Woman's Building, showing the arts which are practiced by women among primitive peoples, especially in North America. This collection includes implements for basket making, pottery, weaving, beadwork, sewing, agricultural implements, and appliances for burden bearing. These are all fully named and explained upon the labels. The theory which has guided Prof. O. T. Mason in the selection of this series is explained by him as follows:

The object of this exhibit is to show the share that women have had in the industrial progress of the world.

In that continual struggle called Progress or Culture men have played the militant part, women the industrial part. A study of modern savagery is a guide to the activities of our own race in primitive times, and this teaches us that women were always the first house builders and furnishers, and that they devised the utensils of the humble apartments. They were the first clothiers, whether in skins at the north or in vegetable fiber nearer the equator. It was the women who went first to the field with baskets that they themselves had fabricated. They gathered the seeds of plants, bore them home on their backs, ground them in rude mortars, and from the flour made their mush or dough. They invented all sorts of fireplaces and ovens, pottery, and cooking utensils, and the many things employed in the serving and consuming of food.

In early society women were literally the first beasts of burden, and it was they that devised all sorts of frames for the carrying of children, and bands and baskets for carrying loads.

Both men and women in savagery are touched with the sense of beauty, the former in the adornment of the person, the weapon, and the canoe, the latter in the technique of basketry, weaving, embroidery, and pottery.

In a small space it was designed to bring together a few examples of primitive woman's work in order to show the paths along which the sex has traveled in time past. The bead work, the embroidery, the personal ornament, the blankets, mats, belts, and looms, the utensils connected with food the conveniences of housewifery, the bark cloth, the delicate handwork in palm leaf, the pottery, the exquisite skin dressing, and implements of Americans, Africans, and Polynesians were silent witnesses of the genius, patience, and skill of women in savagery.

It is hoped that many thousand of those who for the first time viewed a portion of the collections of the National Museum at the Atlanta Exposition will hereafter have the opportunity of seeing the Museum in its entirety in Washington.

MEMORIAL OF DR. JOSEPH M. TONER.

By Ainsworth R. Spofford.

Among the many familiar faces which we have been wont to see gathered in the scientific, literary, and professional assemblies of Washington, there has been no more striking or familiar presence than that of Dr. Joseph M. Toner. Cast physically in a frame of ample mold, with broad, full features, and a massive bald head, his mobile countenance ever ready to relax into a smile, he was a man of marked and engaging and impressive personality.

In attempting to summarize, however briefly and imperfectly, some estimate of our late associate, of his mental characteristics, and of the work which he has done in the world, we may view him in various aspects. We may consider him, first of all, as a student and investigator. He had from very early years a notable zeal for knowledge, and this, unlike the experience of many men who become absorbed in professional routine, may be said to have grown with him through life. Born in 1825 of good old Pennsylvania farmer's stock, the slender intellectual advantages of his boyhood were supplemented by a course of one year at the Western Pennsylvania University and two years at St. Mary's College, in Maryland. Choosing the medical profession for a career, he spent two years at two medical colleges, one in Vermont and the other, Jefferson Medical College, at Philadelphia, taking his degree of doctor of medicine from each. These studious years gave him a considerable knowledge of medical and hygienic literature, and after a brief residence at Harpers Ferry in the practice of his profession, he removed to Washington for a wider field in the year 1855. Here he at once entered upon a practice which became extensive in a very few years. But his habits of mind gave him so strong a bent toward scientific, historical, and literary pursuits that he almost wholly relinquished the active practice of his profession during the later years of his life, prescribing only for the families of a few friends.

Dr. Toner had some admirable qualities in matters of research. His perceptive faculties were quick, his grasp of principles firm, and his devotion to truth was paramount. He weighed evidence and authorities with care, and was often known to change his judgment formed on first impressions upon maturer investigation. At the same time, he

had that strong tendency to build up theories which is common to fertile minds, and had to abandon many which experience and observation failed to substantiate. Perhaps the leading characteristic of his pursuit of scientific subjects was assiduity rather than originality. He pursued every subject which interested him, especially in later years, with an energy which sought out all the means of elucidation within his reach, and he was not satisfied until he had seen and weighed whatever there might be in books and periodicals upon the topic in hand.

We may view him next as a writer, and his contributions to the press were neither few nor small. His first little book, "Maternal Instinct," printed in 1864, at Baltimore, was a serious discussion of the functions and the duties of motherhood, and evinced his earnest bent toward practical views of life. His second book, a "Dictionary of Elevations and Climatic Register of the United States," published at Washington in 1874, was more important. It was the first attempt, so far as known, to put before the public in book form and in alphabetical order the heights above sea level of all cities, towns, and mountains which could be ascertained. These were scattered through very numerous sources of information, in periodicals, Government reports, etc., and to gather them together involved protracted and patient labor, for which Dr. Toner's assiduous zeal in pursuit of a cherished object well qualified him. The book, as published, is open to the drawback that the reader has to consult two alphabets instead of one, and this was caused by the material growing upon him after he had printed off a large portion of the work, which forms the first alphabet. This may be regarded as an object lesson to authors and compilers not to be too hasty in going to press, observing the Horatian rule of a nine years' incubation rather than to bring out an immature production, ever mindful of the Roman maxim, "Litera scripta manet." Still, it is most creditable to the subject of our notice to have been the pioneer in a field of scientific research which has had many more recent publications, under the auspices of various bureaus of the Government connected with military, geological, and geodetic surveys.

In the field of medical and hygienic literature Dr. Toner published, in 1874, "Contributions to the Annals of Medical Progress and Medical Education in the United States," which was brought out by the Bureau of Education. Shortly after appeared his "Address before the Rocky Mountain Medical Association," afterwards expanded into a volume (Washington, 1877), and abounding in historical and biographical material concerning early American physicians and surgeons. He very early made it a special object to collect from the most widely scattered sources all the information existing relating to the men of his profession during the period of the American Revolution. It was this pursuit, occupying several years' labor, which first gave him that strong bent toward historical, and especially biographical, investigations, which finally absorbed nearly all of his time and energies. To gather this

material he went laboriously through the nine folio volumes of Force's American Archives, all the histories of the Revolutionary period, military journals, and personal memoirs, and medical and periodical publications without number. The result was seen in his volume entitled "The Medical Men of the Revolution," containing sketches of the lives and services of nearly twelve hundred physicians and surgeons, an invaluable compilation, which is highly regarded by the profession. He also wrote a "Necrology of the Physicians of the Late War," and "Statistics of the Public Health Associations of the United States."

Dr. Toner at one time made a special study of epidemics, collecting every book and pamphlet on which he could lay hands, and he published the results of his studies in several pamphlets on cholera, smallpox, inoculation, vaccination, and yellow fever. One of his contributions to hygienic literature was "Free parks and camping grounds in summer for the children of the poor in large cities," a pamphlet twice printed, which urges in forcible style the merits of that charity which has organized the "fresh-air funds" in so many cities, and which constitutes one of the best and most useful forms of practical beneficence. One of his incidental contributions to history was "Notes on the burning of theaters and public halls," (1876), occasioned doubtless by the burning of the National Theater in this city. This publication embodies a long and melancholy chronicle of the conflagration of buildings devoted to public assemblies, so often fatal to human life, enforcing the lesson which is never learned, that the sole safety of the community lies in building public edifices fireproof in every part.

In the later years of his life the zeal and energy of Dr. Toner's active mind were largely concentrated upon one subject—the writings and the military and civil career of George Washington. To this he devoted money and time almost literally without stint. The fruits of his Washingtonian researches, which have been embodied in permanent form, comprise more than a dozen books and pamphlets, besides numerous articles in historical and literary magazines and in newspapers. Among the latter were "Wills of the American ancestors of George Washington," in the New England Genealogical Register (1891); "George Washington as an inventor and promoter of the useful arts," published in the memorial volume of the Centenary Celebration of the Patent System in the United States in 1891; "Washington's neighbors;" "The home of Washington;" "Excerpts from the account books of George Washington;" Washington's youth and early career;" "Kith and kin of Washington," and "Some account of George Washington's library and manuscript records, and their dispersion from Mount Vernon," issued by the American Historical Association as a part of its annual papers for 1893. The latter furnishes the only systematic account ever published of the remarkable history of the Washington manuscripts, widely scattered as they are, and it is of permanent value. Besides his own contributions illustrative of the personal and public history of Washington, his char-

acter, habits, social and domestic relations, etc., Dr. Toner edited and published no less than five of Washington's original journals and other writings. These include Washington's "Rules of civility and decent behavior in company and conversation" (1888); "Journal of George Washington's journey over the mountains, beyond the Blue Ridge, in 1847–48" (1892); "The daily journal of Maj. George Washington on a tour from Virginia to the island of Barbadoes in 1751–2" (1892); "Journal of Col. George Washington, across the Alleghany Mountains in 1754" (1893), and "Diary of Colonel Washington for August, September, and October, 1774" (1893). All of these were accompanied by copious notes elucidating the text, describing the topography of the regions traversed by Washington in his various expeditions, identifying the various persons referred to in the narrative, and supplying references to books and authorities bearing upon any of the incidents involved. In some cases these notes far exceed the text in volume, and they are invaluable aids to the historical inquirer. In the case of the Barbadoes journal, Dr. Toner went through all the literature to be found relating to that island, giving lists of the settlers and describing the persons and places visited by the youthful Washington (then 20 years of age) so far as possible.

We may now consider the subject of our sketch as a collector of books and of historical material. The passion of collecting, so common among men of literary tastes and habits of research, but which is so seldom carried to the utilization of their stores by the collectors, was, in the case of Dr. Toner, very early developed after he came to Washington. He was for forty years a familiar figure in nearly all the bookstores, book auctions, and junk shops of this and of some other cities, and though reputed a close buyer, he expended largely in amassing medical, historical, and biographical literature. While his specialty at first was medical science, it soon became enlarged to embrace local history in general and what related to the city of Washington and the District of Columbia in particular. He came to be well known as an authority widely consulted upon matters relating to the national capital.

The writer well remembers the zeal and eagerness of the Doctor, on our first acquaintance in 1862, to avail himself of whatever his friend could contribute to his information respecting the authors, editions, and prices of books. From that time on, the ample mansion on Louisiana avenue was the constant recipient of ever fresh stores of books, pamphlets, and periodicals. In the pursuit of his special object, the biography of early American physicians up to the Revolution, he was gradually led to amass material which ultimately developed into a far wider field, namely, first, the personal history of all American physicians, and, secondly, the biography of all Americans inclusively. He carried out the idea of collecting these materials to a much farther point than is customary even among the most assiduous collectors. His aim included the exploiting of a neglected field. Leaving to larger library collections and to fuller purses the amassing of a great library of biographies, he

set to work to gather up the obscure and forgotten facts, the *disjecta membra* of his subject. With this aim he, for several years, had all the exchanges of the newspaper offices searched for obituary notices appearing from day to day, cut up the contents of biographical dictionaries and directories of Congress, and ransacked all periodicals for biographical sketches. The immense mass of material thus gathered he had mounted upon uniform sheets of paper and arranged in strict alphabetical order, thus embodying for the readiest reference a great mass of fugitive biographical data quite inaccessible to the ordinary inquirer. This valuable index, arranged in two extensive cases of drawers, forms a part of the Toner collection in the Congressional Library.

In like manner the Doctor made another collection of obituaries and biographical sketches of all American physicians commemorated in periodicals.

But the specially cherished design, very nearly fulfilled, of the latter years of his life was the collection of an absolutely complete assemblage of all the letters and other writings, printed and manuscript, of George Washington. Dr. Toner had an idea that everything which Washington wrote was valuable, or would become so, to his countrymen. He found that the printed collections of Washington's writings by Sparks and others, who permitted themselves to amend the grammar, the style, and the orthography of their illustrious subject, are quite untrustworthy as transcripts of what he really wrote. So he had strictly verbatim copies made of every paper in the vast collection of the Department of State, and followed it up by securing exact copies of every original Washington letter found in historical societies and library collections, public and private, throughout this country and in Europe. Where no access to an original could be had, he procured and mounted printed copies, ransacking all American books, periodicals and newspapers he could find, and watching every print of a Washington letter, to seize it for his collection, if not already there. This great thesaurus of Washingtoniana, much the fullest yet gathered in any one collection, he arranged in strict chronological order of the papers, and deposited it in his lifetime in the Congressional Library. Thus was performed a most useful and inestimable service to the historical student.

We may next view our associate as a patron of letters and a public benefactor. He founded and endowed in 1872 a course of public lectures, designed to encourage the discovery of new truths for the advancement of medical science. He conveyed about $3,000 in real and personal property to five trustees, consisting of the Secretary of the Smithsonian Institution, the Surgeon-General of the United States Army, the Surgeon-General of the Navy, the president of the Medical Society of the District of Columbia, instituting thereby "The Toner lecture fund." Ninety per cent of the interest of the fund was to be applied for at least two annual memoirs or essays by different indi-

viduals relative to some branch of medical science, to be read in the city of Washington, under the name of "The Toner lectures," each of these memoirs or lectures to contain some new truth fully established by experiment or observation."

As these lectures were intended to increase and diffuse knowledge, several of them were accepted for publication in the Smithsonian Miscellaneous Collections. The first of the course was by Dr. J. J. Woodward, "On the structure of cancerous tumors," and was printed in 1873. Nine other lectures, by Dr. C. E. Brown-Sequard, Dr. J. M. Da Costa, Dr. W. Adams, Dr. E. O. Shakespeare, Dr. G. E. Waring, jr., Dr. C. K. Mills, and Dr. Harrison Allen, have since been published by the Institution, the last having appeared in 1890. The original fund, of which one-tenth of the annual interest was to be added to the principal and the residue devoted to an honorarium for the lecturers, has grown to over $5,000 by careful investment. It affords a practical example of a wise method of endowment by which even a small sum may be made to yield instruction to large audiences for a series of years.

Dr. Toner gave a gold medal for three years to proficient students in Jefferson College, and a similar medal for many years past, known as the Toner medal, has been awarded at Georgetown University, for the best essay upon some topic in natural science.

His most notable public benefaction, however, was his gift in 1882 of his entire private library to the Government, the first, and thus far the sole instance of any considerable collection being thus bestowed by any private citizen. The gift, comprising about 27,000 volumes—medical, historical, and miscellaneous—besides a multitude of pamphlets and periodicals, was accepted by a special act of Congress, and a bust of Dr. Toner, executed in marble by J. Q. A. Ward, was ordered by the Library Committee, and is placed, with the admirable full length oil portrait of him by E. F. Andrews, in the Library.

Dr. Toner, in addition to this gift in his lifetime, bequeathed by will all his remaining books, manuscripts, pictures, and curios to the Library of Congress, while to the Cambria County Medical Association, at Johnstown, Pa., he has given all duplicates of his books and periodicals.

The Toner collection, while of course it largely duplicates what is already in the Congressional Library, also supplements that collection in many important directions, especially in medical journals, while the special and unique collections in biography and Washingtoniana, already referred to, give to it a great and permanent value. It has been catalogued, excepting a portion of its pamphlets and serials, and while hitherto it has never been adequately or even respectably stored, because of the utter want of room in the Capitol, a place of honor in a corner pavilion of the new Library building, selected by Dr. Toner, will be devoted to the arrangement and preservation of his collection.

It may be hoped that other collectors of valuable libraries and of

manuscripts may emulate the laudable example here set, and perpetuate their names and render their collections in the highest degree useful by endowing the American public, through its Government Library, with the valuable stores which they may no longer use.

Dr. Toner was honored by being chosen president of several societies, including the American Medical Association, the American Public Health Association, each of the two Medical societies of the District of Columbia, the Literary society, the Columbia Historical Society, the Washington National Monument Society, etc. He was offered, but declined, professorships in medical colleges, preferring a more comprehensive field of labor.

In the last few years Dr. Toner had suffered occasionally from internal derangement of certain organs, evincing that his naturally strong constitution was being slowly undermined. But he worked on, putting the best face upon the visitations of disease, until the summer of 1896, when he was in the midst of his vacation at Cresson Springs, Pa., where he suddenly breathed his last, seated in his easy chair, on the 31st of August, 1896.

In conclusion, all who knew him will concur with me that the seventy years of our departed friend and brother represent an earnest, laborious, and highly useful life. To few men, indeed, is it given to win so much of public respect and honor; so much, also, of more tender regard and sympathy. His genial companionship, his warm and widely dispensed hospitality, and his encouraging presence and aid in every good word and work, will be widely missed and long remembered in the city of Washington.

WILLIAM BOWER TAYLOR.[1]

By William J. Rhees.

The record of mortality of the past few years bears the names of an unusual number of eminent scientific men whose contributions to knowledge or whose benefactions to mankind have elicited demonstrations of sorrow in all parts of the civilized world.

It is well to be reminded of the departure from our midst of associates who, though not of wide renown, have possessed sterling merit, and whose useful lives and faithful performance of duty entitle them to grateful remembrance.

Arago, the distinguished secretary of the French Academy, called the attention of his colleagues to the fact that the object of its meetings to eulogize deceased members was not merely to celebrate the discoveries of the more distinguished academicians, but also to encourage modest merit by appropriate recognition, and remarked that "a scientific observer ignored or forgotten by his contemporaries was frequently supported in his laborious researches by the thought that he would obtain a benevolent look from posterity. Let us act," he says, "so far as it depends upon us, in such a manner that a hope so just, so natural, may not be frustrated."

The outline is here presented of the quiet and beautiful life of one whose deeds were unmarked by public notice or applause, unhonored by high titles or station, but who had the respect and love of all his associates, whose faithful and efficient discharge of every duty, whose learning, versatility of resource, self-denying industry, and personal attractiveness entitle him to a place among those whose names should be remembered.

William Bower Taylor, born in the city of Philadelphia May 23, 1821, was the son of Col. Joseph Taylor and Anna Farmer Bower, both of Philadelphia.

Colonel Taylor was a bookbinder, and in 1821 was elected colonel of the Seventy-ninth Regiment of Pennsylvania Militia, which commission he held for seven years. He was well educated, early in life became interested in politics, and was elected to the Pennsylvania

[1] Delivered before the Washington Philosophical Society, May 23, 1896.

legislature. Having removed to his farm near Millville, N. J., for the benefit of his health, he was in 1843 elected to the legislature of that State.

William's mother died while he was quite young. His father provided him with a liberal education, sending him to a Baptist college at Haddington, Pa., then to an academy taught by Prof. Walter R. Johnson, and subsequently to the University of Pennsylvania. Professor Johnson, one of the most learned men of that time, was secretary of the Academy of Natural Sciences, member of the National Institute, professor of physics and chemistry in the University of Pennsylvania, and an able writer on scientific and technological subjects.

In 1835–36 several gentlemen formed a society with the name of The Franklin Kite Club, for the purpose of making electrical experiments. For a considerable time they met once a week at the Philadelphia City Hospital grounds and flew their kites. These were generally square in shape, made of muslin or silk, stretched over a framework of cane reeds, varying in size from 6 feet upward, some being 20 feet square. For flying the kites annealed copper wire was used, wound upon a heavy reel 2 or 3 feet in diameter, insulated by being placed on glass supports. When one kite was up, sometimes a number of others would be sent up on the same string. The reel being inside the fence, the wire from the kite sometimes crossed the road. Upon one occasion, as a cartman passed, gazing at the kites, he stopped directly under the wire and was told to catch hold of it and see how hard it pulled. In order to reach it he stood up on his cart, putting one foot on the horse's back. When he touched the wire the shock went through him, as also the horse, causing the latter to jump and the man to turn a somersault, much to the amusement of the lookers on, among whom was Taylor.

It was this incident and others of a similar character connected with the kite club that turned his youthful mind to science, and especially to electrical phenomena. He made a number of kites himself and also endeavored to make a flying machine. He made a clock wholly of wood, which kept good time.

In 1836 Taylor entered the University of Pennsylvania, became a member of the Philomathean Society, and later its moderator or president. He was graduated in 1840 and commenced the study of law at the university and also in the office of Mr. Rawle, an eminent attorney. He was admitted to the bar of Philadelphia November 15, 1843.

His retiring disposition, studious habits, stern integrity, and high sense of honor were not conducive to securing many clients, and he looked with aversion on the practices of attorneys who were willing to sacrifice truth to gain an unrighteous cause. After four years' experience of an unsatisfactory character as a lawyer, in November, 1848, he became an assistant in the drug store of his brother Alfred, on Chestnut street near Ninth, and remained there until February 1, 1853.

By special invitation of his cousin, Mr. William Ellis, who was in charge of the navy-yard in Washington, he accepted the position of draftsman in the yard February 17, 1853, and a few months later became foreman of the engineer and machinist department. He filled this position acceptably until his resignation, December 31, 1853, receiving a letter from Chief Engineer Henry Hunt, U. S. N., expressing "great regret in his leaving the situation wherein his services and knowledge had been valuable and his deportment most gentlemanly."

In May, 1854, he was appointed by Hon. Charles Mason, Commissioner of Patents, to a temporary clerkship, and on the 1st of April, 1855, was made an assistant examiner in the division under Prof. George C. Schaeffer, the eminent chemist, engineer, and general scientist. Dr. Schaeffer used to relate of this appointment that, finding himself in need of an assistant, he was told by the Commissioner that a young man was in consideration for the place who seemed intelligent and capable but spoke doubtfully as to his own qualifications for the work. "Then please appoint him at once," said Dr. Schaeffer; "he will be just the man I want." The augury was abundantly fulfilled, and was the beginning of a cordial lifelong friendship between the two men, amid various strong differences of opinion. Their debates on matters of high interest were remembered as contests of giants by their hearers.

Mr. Taylor was appointed principal examiner on November 10, 1857, in the class of firearms, electricity, and philosophical instruments. His early legal education and practice fitted him admirably for the position of examiner and enabled him for more than twenty years fully to meet the requirements of an office which Commissioner Mason declared should command the highest order of talent, "where all learning connected with the arts and sciences finds an ample field for exercise and questions of law that tax to their uttermost the abilities of the most learned jurists;" and another Commissioner, Judge Holt, said: "The ability and requirements necessary to a proper discharge of the duties of an examiner must be of a high order, scarcely less than those we expect in a judge of the higher courts of law."

In 1873, the temporary position of librarian being vacant, Mr. Taylor was detailed to this service, on account of his extensive information, and was of great assistance to the examiners through his ability to give them references to aid in making up reports of application for patents.

The Patent Office library was indeed a grand school of instruction and a mine of inexhaustible wealth for a scientific inquirer. Designed as a collection for reference in the examination of applications for patents, in order to determine the question of novelty of invention, it has grown mainly in the direction of technological publications, including full sets of the periodicals devoted to special industrial art and all the more important treatises on machines, arts, processes, and products, in the English, French, and German languages. Besides this, there are the records of foreign patents of inestimable value.

In 1876 Congress provided for the permanent appointment of a librarian in the Patent Office at a much lower salary than that of an examiner, and as Mr. Taylor still held the appointment of principal examiner he was not an applicant for the new position, which was filled by a political appointment. Mr. Taylor then expected to be restored to his former duties as examiner, but by reason of smaller Congressional appropriations, which necessarily reduced the number of appointments, he was unfortunately legislated out of office.

In a letter dated December 6, 1876, in relation to this matter, Professor Henry remarks: "Mr. Taylor, I can truly say, without disparagement to any officer of the Patent Office, is, for extent of knowledge and practical skill in reporting on the originality of inventions, without a superior in the office. He has long been a collaborator of the Smithsonian Institution, is a member of the Washington Philosophical Society, and has achieved an extended reputation as an active contributor to science by his publications. His separation from the Patent Office I consider a public loss, and justice to himself and the interests of the inventors require his restoration."

In a private note to a prominent senator Professor Henry commends Mr. Taylor to his "special attention," and says, "He is held in the highest estimation by all who know him and can appreciate his character. He is not only a gentleman of extensive information and refined culture, but is admirably constituted in regard to intellectual and moral qualities."

While Mr. Taylor was librarian he also acted as examiner of interferences, a very important duty. In fact, Prof. Edward Farquhar, his assistant at the time, remarks that "the various functions he discharged in the office were endless. When a committee was needed to revise the whole classification of the office he was one of the leading members. He was perpetual referee and consulting examiner in a general capacity, as necessarily resulted from his extraordinary knowledge and readiness to impart it, supplying more especially perhaps the principles of science and of law than their practical applications. In the Patent Office, as elsewhere, he was a constant fountain of instruction to all."

In 1872 Professor Henry strongly recommended Mr. Taylor, without his knowledge, for a chair in one of our leading colleges, as one "who from the clearness of his conceptions and the lucidness of his expositions has the elements of an excellent teacher."

Other occasions offered for the employment of Mr. Taylor as a teacher or professor, but he always shrank from assuming the duties of a public instructor and preferred the retirement and privacy of closet study and editorial impersonality.

Early in his residence in Washington he formed the acquaintance and earned the friendship of the leading literary, and especially the scientific men of the city, and with Bache, Henry, Schaeffer, Meigs, and other congenial spirits, founded a scientific club, which, without

constitution, by-laws, or even officers, met weekly at the residence of its members in turn. Hon. Hugh McCulloch, Comptroller of the Currency, afterwards Secretary of the Treasury, was one of this "charmed circle," all of whose members became famous for their service to their country and the world, and in his notable work, Men and Measures of Half a Century, he speaks thus of Mr. Taylor:

> Mr. William B. Taylor held and still holds high rank among the scientific men of Washington. He was then an examiner in the Patent Office, the duties of which he performed with great ability. He is now employed and is doing good work in the Smithsonian. Valuable articles from his pen are sometimes seen, but he avoids notoriety, is rarely seen in society, and seems to be perfectly content with such enjoyments as he finds in doing his duty at the head of one in the divisions of the Smithsonian, and in familiar intercourse with a few personal friends. By those who know him well he is considered the most learned man in Washington.

This opinion was also held and frequently expressed by the late Dr. Welling, president of Columbian University.

Mr. Taylor was one of the founders of the Washington Philosophical Society, which grew out of the Saturday Club just alluded to. He signed the call for the first meeting, requesting Professor Henry to preside, March 12, 1871, and on the organization of the society, March 13, 1871, was elected a vice-president. This office he held until December 17, 1881, when he was elected its fourth president. Between 1871 and 1881 he had presided at forty-five meetings of the society. His first paper was presented June 10, 1871, "On the nature and origin of force," and was published in the Smithsonian Report for 1870, which was issued late in 1871. At almost every meeting of the society he either presented an original communication on astronomical, mathematical, or physical subjects, or discussed with freedom, clearness, and marked ability the papers of others. Among his most important addresses before the Philosophical Society was one in 1878 on the "Life and scientific work of Joseph Henry." This work was peculiarly agreeable to him as an ardent admirer and strong advocate of Henry's policy, his warm personal friend and intimate associate, and of whom he speaks thus: "Few lives within the century are more worthy of admiration, more elevating in contemplation, or more entitled to commemoration than that of Joseph Henry."

On the 5th of May, 1882, he made a report as chairman of a joint committee on the Philosophical, Biological, and Anthropological societies, favoring a scheme of consolidation or union of the scientific societies of Washington, an event which, after a lapse of thirteen years, has only recently been in some degree accomplished.

In February, 1883, a mathematical section of the Philosophical Society was organized, of which he became one of the leading spirits, taking part in every meeting, and on March 24, 1886, he was elected its chairman. On the 23d of October, 1886, he was elected to the general

committee of the society, which position he held until his death, giving to every detail of business the same attention he did to solving the greatest problem of nature.

To the Journal of the Franklin Institute, of which society he was long a member, he contributed, in 1876, a paper on "Physics of the ether," consisting principally of a review of a work by S. Tolver Preston, of London, as well as numerous brief notices or reviews. In the American Journal of Science and Art, New Haven, he published a paper in 1876 on "Recent researches in sound," and in 1885 "On the crumpling of the earth's crust."

His "Kinetic theories of gravitation" was published by the Smithsonian Institution in 1876. An editorial in the American Journal of Science refers to this work as "a valuable historical résumé of the various attempts that have been made by the most eminent philosophers to account for the phenomena of gravitative attraction from the time of Newton to the present day, concluded by a vigorous criticism of the leading theories, in which the author, passing over the consideration of the statical method of explaining gravitation by pressure, finds that kinetic systems are essentially of two classes—the hypothesis of emissions or corpuscles, and the hypothesis of fluid undulations—and proceeds to show that neither form of either hypothesis can satisfy the two Newtonian conditions of a scientific theory—verity and sufficiency."

He became a member of the American Philosophical Society of Philadelphia on the 19th of October, 1877, but does not appear to have contributed to its Transactions.

He was elected a member of the American Association for the Advancement of Science at its twenty-eighth annual meeting, in August, 1880, and at the meeting of August, 1881, was made a fellow of that society. The only paper he contributed to the Proceedings of this society was on "A probable cause of the shrinkage of the earth's crust."

On leaving the Patent Office, he was engaged by Professor Henry to edit his researches on "sound" and "illuminating materials," for the reports of the Light House Board, and in 1878 was appointed by Henry as an assistant in the Smithsonian Institution, a position which he continued to hold for seventeen years, until his death.

On the death of Prof. Spencer F. Baird, secretary of the Smithsonian Institution and United States Commissioner of Fisheries, August 19, 1887, the Washington Philosophical Society, as the senior of the Washington scientific societies, and the one with which Professor Baird had been most closely connected, took initial steps in arranging for a joint meeting to commemorate his life and services. To Mr. Taylor was assigned the theme of "Professor Baird as an administrator," and on account of an intimate knowledge of his great work in the Smithsonian he was eminently fitted to discharge the duty assigned him.

His eulogy of Professor Baird was published in the Bulletin of the Philosophical Society, Vol. X, 1888; also in the Smithsonian Miscellaneous Collections.

He was president of the District of Columbia Alumni Association of the University of Pennsylvania, and presided at its annual banquets.

During the life of Professor Henry no formal office existed as "editor" of the Smithsonian publications. Every article submitted for publication was carefully examined by Professor Henry himself, all doubtful points discussed with the authors, and every line closely scrutinized in the proof sheets, independent of, and in addition to, the examination made by his assistants. Mr. Taylor's distinctive labors as "editor" commenced with Professor Baird's accession to the secretaryship.

Perhaps very few persons have an idea of the scope of this part of the operations of the Smithsonian. It may be well, therefore, to refer briefly to it, as by Professor Henry it was considered the most important part of the operations of the institution, he giving it the first place in his reports, because he believed it was to its *publications* mainly that the institution owed recognition and fame throughout the world.

During the last half century the relations of the Smithsonian Institution considered as a publishing agency, to the scientific public of America has been essentially that held by the great European academies to the scientific men of Europe. So far as works of great importance, of high cost, and appealing to a limited but the most learned class, are concerned, its record is excelled by none, if indeed equaled by any other establishment.

Of the Smithsonian publications, Mr. Taylor thus speaks in his eulogy on Henry:

> To attempt the recapitulation of the various branches of original research initiated or directly fostered by the institution would be to write its history. Scarcely a departm nt of investigation has not received, either directly or indirectly, liberal and efficient assistance. The various works submitted to the institution, even after approval, entail a vast amount of unrecognized and little appreciated labor in the elimination of obscurities, of redundancies, or of personalities, and in the pruning of questionable metaphors, of perfect or hasty generalizations, or of incidental inaccuracies of statement or inference.

The most important duty Mr. Taylor performed as editor while at the Smithsonian was the collection and publication of the Scientific Writings of Professor Henry. To this labor of love, for which he was perhaps better fitted than any other person, he gave a year or two of untiring devotion. He was scrupulously careful to verify every reference and to recalculate every mathematical formula used by Henry in any of his papers, and without his abundant knowledge of Henry's researches and his familiarity with the whole history of discovery in electricity and magnetism he could not have produced this valuable work.

While Mr. Taylor's learning and skill in book making were invaluable to the Smithsonian Institution, his labors were not confined to those of an editor. As early as 1866 he became one of the collaborators of the institution, to whom was referred much of its scientific correspondence, and this relation he held until 1878, when to him was assigned the entire charge of the consideration and discussion of matters pertaining to physics.

This part of the operations of the institution, while attracting no public attention, produces important results in the diffusion of knowledge. Scarcely a day passes in which communications are not received from various parts of the country, giving accounts of discoveries, or seeking information relative to some branch of knowledge. The rule was early adopted to give respectful attention to every letter received. Many of these communications are of such a character that, at first sight, it might seem best to treat them with silent neglect; but the practice was observed of stating candidly and respectfully the objections to such propositions, and to endeavor to convince their authors that their ground was untenable.

Mr. Taylor had a keen sympathy with mere theorists, as well as with inventors; with those who supposed they had discovered new systems of the universe, as well as those who endeavored to contrive machines to realize perpetual motion. To all these he had the rare faculty of being able to detect and expose their fallacies without hurting their pride or wounding their sensibilities, and, although they might not accept his conclusions, they always seemed grateful for his criticism and honored his candor.

From what has been said as to the engrossing occupations of Mr. Taylor, it can readily be inferred that his own published writings were few. Most of his work was fragmentary and discursive, and while voluminous in the aggregate, was very much condensed and epitomized in each separate case.

His principal works were:

Scriptural Authority of the Sabbath, 1851
The Nature and Origin of Force, 1870.
Refraction of Sound, 1875.
Kinetic Theories of Gravitation, 1876.
Henry and the Telegraph, 1878.
Memoir and Scientific Work of Joseph Henry, 1878.
Physics and Occult Qualities, 1882.

In his history of Henry and the Telegraph, Taylor treats fully of the growth of the electric telegraph, and shows "that prior to Henry's experiments in 1829 no one on either hemisphere had ever thought of winding the limbs of an electro-magnet on the principle of the bobbin, and not until after the publication of Henry's method in January, 1831, was it ever employed by a European physicist." Taylor, however, does not claim for Henry exclusive honor for the invention of the telegraph;

he shows that no single individual is entitled to that distinction. He says: "It was, in fact, a growth rather than an invention, the work of many brains and of many hands; but amid the galaxy of brilliant names who prepared the way for success and organized the triumph for the execution of skillful artisans, none stands higher or shines with more resplendent luster than that of Joseph Henry."

Although so truly a "scientific" man, Taylor did not engage in original research and experiment, a field which, if he had entered, there can be no doubt of his brilliant success. It is possible, however, that he was better fitted for the sphere of action in which he engaged. It may be true that "the genius which qualifies a man for enlarging the boundaries of science by his own inventions and researches is of a very different class from that which confers the ability to elucidate, in a simple and systematic course, the order and connection of elementary truths."

Taylor's mental characteristics were of a very high order; few men have been better endowed by nature or developed by study. He not only had quick perceptions to grasp the arguments or meaning of others, but he could find in them relations and suggestions which they had not themselves seen. He was extremely exact and precise in stating his own views and in making his meaning clear.

His writings are distinguished as being not merely a digest of ideas which he had acquired from the perusal of books of others, but an able analysis of the work of every author which exercised any influence on the topic he had under discussion.

One trait of his character was the thoroughness with which he pursued any inquiry, as he was never satisfied until he had learned all that could be ascertained in regard to it. A remarkable memory enabled him in his daily work to profit from his extensive researches.

As a conversationalist, it seemed as if any subject, even casually started, had been the special theme of his thinking. He could adapt himself to and equally please the profound philosopher, the crude schoolboy, or the hard-working mechanic.

He was particularly fond of optical experiments, drew elaborate diagrams and plans of improved instruments, especially the stereoscope, and made an unusually large collection (20,000) of stereoscopic views.

He frequently urged the importance of the establishment of a bureau for indexing scientific publications, and considered the devotion of a fund for this purpose by a millionaire who wished to secure perpetual fame as far more likely to secure his object than by adding another library or even a university to those now existing.

Many works with which Mr. Taylor's name has never been connected owed a large part of their merit and success to materials he furnished and to his advice, revision, and criticism. The labor of hand and brain which might have been employed in building up his own fame was freely given to all who sought it. He was very averse to writing for

compensation for the public press, not wishing, as he said, to be in the category of "penny-a-liners."

He was an erudite classical scholar, and his very latest reading was in old Latin tomes. But while he enjoyed communion with the scholars of antiquity, he was also thoroughly acquainted with the scientific discoveries of the present day, diligently perusing the transactions of learned societies and leading periodicals from all parts of the world as they reached the Smithsonian Institution, which is distinguished as being the repository of more of this class of literature than any library in the country. He kept well informed as to public questions and the discussions of political economy and of general current topics.

He was a great lover of poetry, and made a large collection of the lives and works of poets, among whom Shelley seems to have been his favorite. He also wrote numerous notes and comments on poetical works.

One of his literary amusements was the preparation of a story of "The wars of the angels," found scattered through Milton's Paradise Lost. Mr. Taylor cut up copies of the work, and selecting all references to this phase of the poem, he neatly pasted them on loose pages, thus making an interesting narrative, which he named "The wars of the angels," and which he thought of publishing, with critical notes and comments, but the plan, beyond the work referred to, was never carried out.

He was a great reader and spent most of his leisure in his library, which was unusually large and valuable. While mainly scientific in character, it contained special collections of much value and extent on ecclesiastical history, translations of and commentaries on the Bible, the Sabbath, myths, creeds, spiritualism, fine arts, besides a very large number of grammars and dictionaries.

Among his specialties he had a complete collection of editions of Reynard the Fox, another of Ornamental Alphabets, another of "Facetiæ," and many thousands of engravings and photographs. He spared no pains or expense to make the specialties in which he was interested as complete as possible.

Mr. Taylor's life, apart from his scientific and literary work, was unusually quiet, serene, and uneventful. He seemed wholly destitute of personal ambition, and was always content to receive but never to seek preferment. His motto seems ever to have been "I serve." He was truly a slave to routine duty, and the bright light of his intellect was hidden by the bushel of official exactions. In feelings and opinions he was a decided conservative; while sympathizing with advance movements in social progress, his tastes and acquaintance with the past led him to be cautious of novelties or radical changes in the established order of things. He had no patience with demagogues and no sympathy with socialists. He never mingled in public affairs, never voted, and took no part in or even attended public gatherings for the promotion

of general welfare or special charities. He never married, and unfortunately had no realization of the happiness, the incentive, the dignity, and the honor of the home and family.

He had great detestation of frauds, shams, and dishonesty of all kinds, and moreover had the courage of his convictions in denouncing imposters and charlatans. He was not swayed by an array of numbers or dignitaries in forming his opinions, but believed with the great philosopher Galileo, that "In questions of science the authority of a thousand is not worth the humble reasoning of a single individual."

He was courteous, kind, and unselfish in a marked degree, and was uniformly cheerful and dignified.

He was fond of the drama, and this appears to have been the principal source of his recreation.

His penmanship was particularly delicate, refined, and distinct, and is identically the same for the last forty years of his life. He left an immense mass of manuscript notes on every subject to which he had given attention. Economical to a degree almost approaching parsimony, he wasted nothing, and condemned and despised extravagance or display either in private or in public life.

Dr. Edward Farquhar has contributed the following remarks in regard to Mr. Taylor's scientific characteristics:

> Of the whole philosophy and theory of evolution, whether embodied in the researches and suggestions of Darwin, or the more generalized thought of Spencer, he was so complete a master that he stood as an expositor of it, perhaps as the expositor, to a very interested circle of acquaintance.
>
> Atomic theory was one of his most peculiar haunts, linguistics, especially comparative philology, might have been taken for his natural destiny; psychology was a familiar region of thought and of close observation; rhetoric and style, of minute analysis and discrimination; while mathematical principles he was particularly fitted to expound because he grasped them not in mere specialty, but in their relations with truth in general.

Mr. Lester F. Ward, one of the most learned and distinguished members of the Washington Philosophical Society, has remarked:

> Mr. Taylor, although primarily a physicist, was widely informed on all the deeper topics of general science. His mind possessed a delicate sensibility to suggestion from others, and was influenced wholly by the inherent merit of the suggestion and not at all by the supposed competency or incompetency of the person making it. Still, on most questions, he had settled convictions, and on nearly all important subjects he possessed original ideas, the results of prolonged independent thought. His conversation was particularly charming from the fact that it combined great learning and originality with the utmost simplicity and a complete absence of dogmatism. In a word, his entire character illustrated how extremely liberal genuine wisdom can afford to be.

Mr. Taylor enjoyed good health nearly the whole of his life, though for many years he had not taken the customary leave of absence from

office, for rest and recreation. An attack of the grippe in 1894, however, seemed to enfeeble him and he never regained his former vigor. His last illness was brief. After much suffering from an incurable malady, and submitting to a surgical operation, he died in Washington on February 25, 1895, in the seventy-fifth year of his age, and his remains were buried in Woodlawn Cemetery, Philadelphia, his native city.

> "O, good old man! how well in thee appears
> The constant favour of the antique world,
> When service sweat for duty, not for meed!
> Thou art not for the fashion of these times,
> Where none will sweat but for promotion."

JOSEPH PRESTWICH.[1]

By H. B. Woodward.[2]

Among the more distinguished of the second generation of British geologists—a band comprising such men as Godwin-Austen, Falconer, Morris, Edward Forbes, Egerton, Jukes, Ramsay, and Daniel Sharpe—the subject of our present memoir has long outlived each one of them, and the close of his life, at the advanced age of 84, severs the most prominent link which connected the geologists of the present day with the old masters.

Joseph Prestwich was born at Pensbury, Clapham, on March 12, 1812, and was descended from an old Lancashire family. One of his ancestors, Sir Joseph Prestwich, Bart., was an active fellow of the Society of Antiquaries, and a manuscript written by him about the year 1798, dealing with the subject of earthquakes, was published by Joseph Prestwich in the Geological Magazine for 1870. At one time Prestwich entertained the idea of claiming the baronetcy, which his father had declined to take up, but, owing to the loss of documents, this intention was abandoned.

Receiving his early education partly in London, partly in Paris at a school attached to the College Bourbon, and partly under the famous Dr. Valpy at Reading, Joseph Prestwich completed his studies at University College, London. There he learned chemistry under Dr. Turner and natural philosophy under Dr. Lardner, and he gained some acquaintance with mineralogy and geology from a few lectures included in his course by the professor of chemistry. That he had a leaning toward experimental science was evident, for he subsequently formed a laboratory, which he maintained until about the year 1860. His own tastes would have prompted him to adopt a profession, but circumstances caused him to enter his father's business of wine merchant, and in this he was closely occupied for about forty years, until 1872, when he retired from his office in Mark Lane.

[1] From Natural Science, London, Vol. IX, 1896, pp. 89–98.

[2] For some particulars relating to Sir J. Prestwich we are indebted to an article printed in the Biograph for December, 1881, and reprinted with additions and revisions in the Geological Magazine for June, 1893.

The brief introduction to geological science which Dr. Turner had given was destined to bear the most excellent fruit. Prestwich was thus led to examine the collections of fossils in the British Museum; and the works of Conybeare and Phillips, of De la Beche and Lyell, became his text-books.

Entering the field of geology, as he tells us, for relaxation from the cares of commercial life, he had in his early years only such time as could be snatched from business at intervals, and chiefly on Saturdays and Sundays. Fortunately his duties led him into various parts of the country, and every opportunity was taken of making acquaintance with the physical features and structure of the districts he visited. It is, however, wonderful to find how much he achieved, how early he had mastered the principles of geology, and how sound were his interpretations of facts.

His holidays during the years 1831 to 1833 were for the most part spent in the region of Coalbrook Dale, and the results of his researches were communicated to the Geological Society of London in 1834 and 1836. This work was published in full in the Transactions of the society, and looking at it now it may be regarded as a model of what a memoir should be on such a subject as the coal field and its associated strata. The Silurian and Carboniferous rocks, the new red sandstone, the igneous rocks, and the drifts were all duly described, and what is more remarkable, considering the youth of the author, the superficial extent of the various rocks was shown on a map of the scale of one inch to a mile in a manner differing in no very important particulars from the subsequently published map of the Geological Survey. The structure of the area and its faults were carefully depicted, while the organic remains which Prestwich had obtained were described with the aid of his friend, John Morris. So highly, indeed, would we speak of this work that had the author done nothing subsequently we believe it would have entitled him to a permanent place on the roll of those geologists who have rendered distinguished service.

In 1835 another paper was read by Prestwich before the Geological Society on the ichthyolites of Gamrie in Banffshire, and this was his first published work. In 1837 he supplemented it with observations on the drift deposits, including those of Blackpots, and he noted the existence of a raised beach.

These early studies give a good idea of the bent of his mind, his attention being given to stratigraphical geology and to the physical conditions under which strata were accumulated. In later years he turned again to the coal measures in other regions, especially in Somerset, and to their possible underground range in the southeastern counties, while the subjects of drifts and raised beaches gained eventually more and more of his attention.

Prestwich was elected a fellow of the Geological Society in 1833, when Greenough was president; and he first became a member of coun-

cil in 1846, when Murchison was president and Sedgwick, Buckland, Fitton, Lyell, De la Beche, and others were his associates.

He had now for some years been particularly occupied in what may be considered his chief work—the elucidation of the Eocene strata of the London and Hampshire basins.

Commencing in the London area he zealously traversed the country wherever the Lower Tertiary strata were to be found, and hardly an outlier of any importance escaped his observation. Mr. Whitaker, who, more than any other man, has followed in the footsteps of Prestwich over this large region, referred in 1872 to the literature of the subject, and remarked that the period 1841 to 1860 "might well be called the 'Prestwichian period,' from the author who first clearly made out the detailed structure of the London Basin."[1]

After certain preliminary studies the interest and difficulties of the subject, as Prestwich himself relates, speedily induced him to take it up with more earnestness and determination, and eventually led him to extend his inquiries over an area which at first he never contemplated. With true enthusiasm he remarked, "The Tertiary geology of the neighborhood of London may be wanting in beauty of stratigraphical exhibition and in perfect preservation of organic types, but in many of the higher questions of pure geology—in clear evidence of remarkable physical changes—in curious and diversified palæontological data, however defaced the inscriptions, which is, after all, but a secondary point, few departments of geology offer, I think, greater attractions." These statements were made in 1849 when De la Beche handed to him the Wollaston medal, which had been awarded by the council of the Geological Society. He had then completed but a portion of those labors which established his reputation as the leading authority on our Tertiary strata. Having already extended his researches from the London to the Hampshire Basin, he subsequently followed the strata into Belgium and France, correlating the divisions he had made in this country with those established abroad by Dumont and D'Archiac.

His great aim was, by studying in detail the lithological characters of the strata and their fossils, to mark out the main subdivisions in the Eocene system, and to picture the ancient physical conditions which attended their formation. By following the strata from point to point he was enabled to record the mineral changes which many of the subdivisions undergo, and to note the changes in fauna that accompany these variations in sedimentary condition. He also showed how differences in the flora in certain formations pointed to distinct land areas. Thus were fossils employed, as they should be in geological investigations, in interpreting the physical conditions of the strata after the stratigraphical features had been determined, and in aiding the subsequent correlation with distant deposits.

[1] Mem. Geol. Survey, Vol. IV., page 395.

In his earlier papers on Eocence formations he dealt with the age and relations of the London Clay and Bagshot Beds. He proved the connection of the London Clay and Bognor Beds, and showed that they were older than the clays and sands of Bracklesham and the clays of Barton. He subdivided the Bagshot Beds, and correlated with them certain strata in Hampshire and the Isle of Wight. Subsequent researches by Mr. Starkie Gardner, Mr. Monckton, and Mr. Herries, have thrown doubt on the correlation of the Upper Bagshot Sands of Surrey with those of Hampshire (the Headon Hill Sands); and in a later work[1] Prestwich agreed that the Upper Bagshot Sands of the London area might be partly or wholly of Bracklesham age. Ready at all times to accept corrections when assured of their accuracy, he was also not unwilling to admit changes in classification when the alteration was for the general convenience. Thus he adopted the term Oligocene for strata previously grouped as Upper Eocene. He did not, however, agree with Mr. Whitaker in his proposal to form a separate division, termed the Oldhaven Beds, from strata in part grouped by Prestwich with the basement bed of the London Clay, and in part with the Woolwich and Reading Series.

Continuing his researches Prestwich described in full detail the strata between the London clay and chalk, giving the names "Thanet Sands" and "Woolwich and Reading Series" to strata previously grouped together as the "Plastic Clay Formation." Referring to the important series of Eocene memoirs, which he had completed in 1854, Edward Forbes remarked, "These remarkable essays embody the results of many years' careful observation, and are unexcelled for completeness, minuteness of detail, and excellence of generalization."[2]

A popular account of the Eocene strata and of the superficial deposits that occur in the neighborhood of London was given by Prestwich in 1854 and 1856, in the course of three lectures on the geology of Clapham, and these were published a year later under the title of The Ground Beneath Us. Clearly and pleasantly written, this little work was well calculated to arouse the interest of the reader, and at the time of its publication it was one of the best introductions to geology which it was possible to place in the hands of a beginner.

While Prestwich gave his attention in the main to pure science, he did not neglect the important applications of knowledge. By his publication in 1851 of A Geological Inquiry Respecting the Water-bearing Strata of the Country around London he came to be recognized as the leading geological authority on the subject; and in 1867 he was appointed a member of the Royal Commission on Metropolitan Water Supply.

He was elected a fellow of the Royal Society in 1853, and vice-president in 1870; in that year also he became president of the Geological Society. In his second address to that society in 1872 he gave

[1] Geology, Vol. II, page 364.

[2] Address to Geological Society, 1854.

an excellent and oft-quoted account of the growth of London as dependent on the means of obtaining a supply of water. In the same address he referred to the many aspects of geological science, and remarked that, "While treating of these abstract and philosophical questions, geology deals also with the requirements of civilized man, showing him the best mode of providing for many of his wants, and guiding him in the search of much that is necessary for his welfare. The questions of water supply, of building materials, of metalliferous veins, of iron and coal supply, and of surface soils, all come under this head, and constitute a scarcely less important, although a more special, branch of our science than the paleontological questions connected with the life of past periods, or than the great theoretical problems relating to physical and cosmical phenomena."

He reverted to the subject of water supply soon after he came to reside in Oxford, publishing a pamphlet on the geological conditions affecting water supply to houses and towns, with especial reference to that city. He dealt in 1874 with the subject of the proposed tunnel between England and France, and his essay, published by the Institution of Civil Engineers, gained for him the Telford medal.

At an earlier period he superintended the inquiries concerning the Bristol and Somerset coal field for the Royal Coal Commission, and prepared reports (published in 1871) on that area, and on the probability of finding coal under the newer formations of the south of England. With regard to the latter subject he took a favorable view, and observed that we might look for coal basins "along a line passing from Radstock, through the vale of Pewsey, and thence along the North Downs to Folkestone." The results of the Dover boring have so far justified this conclusion, which was based on the acute geological reasonings of Godwin-Austen. At various periods, moreover, he described important well sections at Yarmouth, Harwich, Kentish Town, and Meux's brewery in London.

The completion of his labors among the Eocene strata allowed Prestwich to devote more time to the newer deposits which had on various occasions engaged his attention.

He had examined the Norwich Crag as early as 1834, in company with S. Woodward, and he then found a tooth of *Elephas meridionalis* in the Thorpe pit. Accompanied by Godwin-Austen, Morris, and Alfred Tylor, he had in 1849 made a short excursion into the crag district, and he then suggested that the fossiliferous shell bed which overlies the Red Crag at Chillesford might represent the Norwich Crag. He returned in 1858 to the subject of the crag in his description of the remnants of that deposit which occur at Lenham and other places on the chalk areas of the North Downs. Although the species of fossils were but doubtfully identified by Searles Wood, and some authorities came to regard them as probably Eocene, yet Prestwich contended for their Pliocene age, and his views have been fully confirmed by the subsequent observations of Mr. Clement Reid.

In 1868 he communicated to the Geological Society the first part of his elaborate work On the Structure of the Crag Beds of Suffolk and Norfolk. The three parts were published in 1871. They contained the results of his long labors, and, as he remarks, "The greater part of my observations date, in fact, so far back as from 1845 to 1855."

In some respects this was unfortunate, since the author had been too much occupied to work out the results of his observations while they were quite fresh in his mind; moreover, he did not fully realize how much had been done by previous observers. In omitting to notice in detail work that had been previously published, he observed, "I may be further justified in this course by the circumstance that my own researches are in great part anterior to most of the papers in question"—a plea that fails to satisfy the worker who is keen on priority of publication. One noteworthy result of this was the introduction into Norfolk of the term "Westleton Beds," for strata previously described at certain localities by Wood and Harmer under the name of Bure Valley Beds. It has now been clearly shown that the Bure Valley Beds (of the Bure Valley) are of earlier age than the Westleton Beds (of Westleton), the former being linked with the Norwich Crag (Pliocene), and the latter being rightly regarded by Prestwich as Pleistocene. What may be the particular horizon in the Pleistocene group of the Westleton Beds is still a matter of dispute. No fossils have yet been found in the Westleton Beds at Westleton, and it is therefore a matter of great uncertainty as to how far correlation is justified with the other unfossiliferous pebbly gravels of the eastern and southern counties of England. Prestwich has, however, published a series of papers on these scattered deposits, and the facts which he has made known must always prove of value, while his theoretical conclusions, which have added largely to the interest taken in the subject of gravels, can not fail to have beneficial results.

The importance of an attentive study of the Glacial Drift and other superficial deposits was pointed out by Joshua Trimmer, and he was followed by S. V. Wood, jr., who, pursuing the subject in great detail, personally surveyed on the 1-inch ordnance maps large areas of the eastern counties, and stimulated others, like Mr. F. W. Harmer, in Norfolk, and the Rev. J. L. Rome, in Lincolnshire, to cooperate with him. Prestwich, meanwhile, had made particular observations here and there, and chiefly between the years 1855 and 1861, in Holderness, at Mundesley, Reculvers, Hackney, Salisbury, and Brighton. He devoted his attention more especially to fossiliferous deposits of valley drift and to raised beaches. He described a few sections of Glacial Drift, but did not yet enter into any general discussions with regard to the classification of our Pleistocene deposits.

His most important researches among the latter deposits were unquestionably those relating to the valley or river gravels, and to the occurrence in them of flint implements and certain fossil mammalia.

The discoveries, made known in 1847 by Boucher de Perthes, of flint weapons together with teeth of the mammoth in the gravels of the Somne Valley had attracted the attention of Dr. Falconer, and he induced Prestwich, in 1859, to investigate these most interesting deposits. After careful study, in which he was joined by Sir John Evans, he satisfied himself that the flint implements were the work of man, that they occurred undisturbed in beds of sand and gravel, together with remains of mammoth, *Rhinoceros tichorhinus*, *Hyæna spelæa*, and other Pleistocene mammalia.

These researches were in part stimulated by the discovery, in 1858, of flint implements with bones of extinct animals in Brixham Cave; and they served to confirm the previous and long-neglected discovery of flint implements in Kent's Hole, Torquay, made by the Rev. John MacEnery. Sir John Evans, moreover, directed attention to the forgotten discovery of flint implements at Hoxne, in Suffolk, a fact originally published in 1800. No time was, therefore, lost in visiting this and other English localities, and the results were brought before the Royal Society in 1859 and 1862. At the conclusion of his second paper, Prestwich remarks: "That we must greatly extend our present chronology with respect to the first existence of man appears inevitable; but that we should count by hundreds of thousands of years is, I am convinced, in the present state of the inquiry, unsafe and premature." In his latest observations on the subject he has expressed his belief "that Palæolithic man came down to within 10,000 to 12,000 years of our own time," while he may have had, "supposing him to be of early Glacial age, no greater antiquity than, perhaps, about from 38,000 to 47,000 years." (Collected Papers, p. 46.)

For his original researches on the valley deposits yielding implements and weapons of Palæolithic man, Prestwich was awarded a royal medal by the Royal Society in 1865. The full report on the exploration of the Brixham Cave was prepared by Prestwich and communicated to the same society in 1872, the animal remains being described by Busk, and the flint implements by Sir John Evans.

About the time of his retirement from business, in 1872, Mr. Prestwich married the niece of his old friend Dr. Falconer, and settled in a house (Darent Hulme) which he built at Shoreham, near Sevenoaks. He was not, however, to retire from active geological work. After the death of John Phillips, in 1874, he was offered the professorship of Geology at Oxford, and this he accepted, now spending a portion of his time in that city. The duties of a geological professor at Oxford are not, perhaps, very onerous, but Prestwich filled the office with dignity and advantage to the university. Phillips, who excelled in eloquence, had at times no more than three students, as geology received no encouragement from the university authorities. Few geologists of note have, therefore, hailed from Oxford as compared with Cambridge, and we call to mind only Edgeworth David (now professor of geology in the Uni-

versity of Sydney) and F. A. Bather (of the Geological Department, British Museum), who, trained in geology under Prestwich, have since gained distinction. His field excursions, however, were always highly appreciated by many who found no time to pursue the science in after life.

Various papers proceeded now from his pen; he dealt with the much discussed origin of the parallel roads of Glen Roy, and he wrote on the agency of water in volcanic eruptions, believing that the water was but a secondary cause, and that the phenomena were dependent on the effect of secular refrigeration. He dealt also with the problem of the thickness of the earth's crust, and published an elaborate paper on underground temperatures.

He also made a special study of the Chesil Beach, coming to the conclusion that it was a wreck of an old and extensive raised beach, of which a remnant still exists on Portland. His view concerning the comparatively recent date of the Weymouth anticline has not, however, proved to be sound.

During his term of professorship, Prestwich wrote his well-known work entitled "Geology—Chemical, Physical, and Stratigraphical," in two volumes, published in 1886 and 1888, a work admirably illustrated. In the first volume he remarked that among geologists two schools have arisen, "one of which adopts uniformity of action in all time, while the other considers that the physical forces were more active and energetic in past geological periods than at present." Advocating this latter teaching he felt he should be "supplying a want by placing before the student the views of a school which, until of late, has hardly had its exponent in English text-books." He indeed protested on many occasions against the doctrine of uniformity of action, both in kind and in degree. Such, indeed, was the teaching of Ramsay in his presidential address to the British Association at Swansea in 1880. That geologist referred to the great changes, of which we have evidence in comparatively late geological times, in the upheaval of mountain chains and in the vicissitudes of the Glacial period; and, in regard to volcanoes, he believed that "at no period of geological history is there any sign of their having played a more important part than they do in the epoch in which we live." Ramsay based his argument on the record of the rocks, and, leaving out of consideration cosmical hypotheses, he concluded that, from the epoch of our oldest known rocks down to the present day, "all the physical events in the history of the earth have varied neither in kind nor in intensity from those of which we now have experience." This conclusion may be taken to mean that any kinds of physical change that have happened in the past, since the earliest rocks were laid down, may happen again, and we believe that this is the real view of the Uniformitarian. Mr. Teall again, in 1893, forcibly urged the claims of the Uniformitarian school, pointing out "that denudation and deposition were taking place in pre-Cambrian times, under chemi-

cal and physical conditions very similar to, if not identical with, those of the present day." All geologists seek to interpret the past by the light of the present; but while Uniformitarians (as they are called) demand time unlimited, their opponents, sometimes spoken of as Catastrophists, would rather infer a greater potency in the agents of upheaval or denudation than grant an unlimited amount of time.

As Prestwich puts it: "Not that time is in itself a difficulty, but a time rate, assumed on very insufficient grounds, is used as a master key, whether or not it fits, to unravel all difficulties. What if it were suggested that the brick-built pyramid of Hawâra had been laid brick by brick by a single workman? Given time, this would not be beyond the bounds of possibility; but Nature, like the Pharaohs, had greater forces at her command to do the work better and more expeditiously than is admitted by Uniformitarians." (Collected Papers, 1895, p. 2.) He maintained that modern estimates of denudation and deposition and of rates of upheaval and depression were no test of what happened in the past; that, in fact, the potency of agents had diminished. Referring to the Glacial period, in his inaugural lecture on "The past and future of geology," delivered at Oxford in 1875, he thus expresses himself: "This last great change in the long geological record is one of so exceptional a nature that, as I have formerly elsewhere observed (Phil. Trans., 1864, p. 305), it deeply impresses me with the belief of great purpose and all-wise design in staying that progressive refrigeration and contraction on which the movements of the crust of the earth depend, and which has thus had imparted to it that rigidity and stability which now render it so fit and suitable for the habitation of civilized man; for, without that immobility, the slow and constantly recurring changes would, apart from the rarer and greater catastrophes, have rendered our rivers unnavigable, our harbors inaccessible, our edifices insecure, our springs ever varying, and our climates ever changing; and while some districts would have been gradually uplifted, other whole countries must have been gradually submerged; and against this inevitable destiny no human foresight could have prevailed."

His great text-book on geology, to which we have alluded, will remain as a monument of his zeal and untiring labor. On its completion he resigned his professorship and retired to his quiet home among the chalk hills of Kent. There, however, he maintained his interest in his favorite science and continued to labor to the very end of his days. Soon after leaving Oxford, in 1888, he was called upon, as our leading geologist, to preside over the meeting of the International Geological Congress, which then held its fourth session in London.

The study of the drifts of the south and southeast of England now absorbed most of his time, and he devoted more attention to the grouping of the later superficial deposits and to the great physical changes to which they bear witness. His ideas on all these topics have not

met with the unanimous approval of geologists, nor was such a happy result to be expected on a complex subject where there is great room for diversity of opinion. His views on the primitive character of the flint implements of the chalk plateau of Kent have, however, opened up a new and interesting inquiry, and one more likely perhaps to gain support than his evidences of a submergence of Western Europe at the close of the Glacial period, and their bearing on questions relating to the tradition of a flood.

It is, however, yet early to judge of these controverted questions. They require further detailed study and impartial consideration, and whatever conclusions be eventually accepted, there can be no doubt that the patient and enthusiastic labors of Prestwich on these most difficult problems will have largely contributed to their solution.

Throughout his long life Prestwich felt deeply indebted to geology, and, as he once put it, not merely because it was a source of healthful recreation, but "for its kindly and valued associations, and above all, for the high communing into which it constantly brings us in the contemplation of some of the most beautiful and wonderful works of the creation."

In the early part of the present year Her Majesty conferred the honor of knighthood upon him, but Sir Joseph Prestwich was too feeble in health to accept it in person. He died on June 23, and was buried in the churchyard of Shoreham, near Sevenoaks, not far from his pleasant home of Darent Hulme.

HENRY BRUGSCH.[1]

By G. Maspero.

Henry Brugsch was born in Berlin on February 18, 1827, and he died there on September 9, 1894. He has himself told in his Recollections what he wished to have known of his life.[2] To that book I refer those who wish to know what the man was, and shall content myself with speaking here of what we owe to the scholar.

The early years of his scientific career were entirely devoted to the study of the language and the popular script of the ancient Egyptians. He began these studies while still at college, alone and without any help save that of the aged Passalacqua: but he progressed so rapidly and so well that in 1848, when but 21 years old, he published his first memoir, Scriptura Ægyptiorum Demotica, ex Papyris et Inscriptionibus Explanata,[3] in which he gave the first outlines of Demotic grammar—imperfect, it is true, and following the principles of exaggerated phoneticism which F. de Saucly had endeavored to introduce into that branch of Egyptology. Lepsius criticised the attempt of the young man with unmerciful severity.[4] E. de Rougé was more indulgent. He saw as well as did Lepsius the serious faults of the book, but he gave full justice to the power for work and the intelligence of the author, and he tried to show him the right way. In an article entitled, "Sur les éléments de l'écriture démotique," he showed him the points in which his system was wrong, and taught him the method by which he might obtain with certainty the decipherment of the signs and the construction of the phrases.[5] Brugsch received the lesson with gratitude, and immediately corrected his method of study. From this time he was inspired by the principles of de Rougé, and each

[1] Translated from Actes du Dixième Congrès International des Orientalistes, session de Genève, 1894. Quatrième partie. Leide, 1897. Pp. 95–102.

[2] Mein Leben und mein Wandern. 8°. 1894.

[3] With the statement: Scripsit Henricus Brugsch, discipulus primæ classis Gymnasii Realis quod Berlini floret.

[4] Compare the preface of E. F. August, director of the gymnasium, to the Scriptura Ægyptiorum Demotica.

[5] E. de Rougé Lettre à M. de Saulcy sur les éléments de l'ecriture demotique, in the Revue Archéologique le Série. 1848. Vol. V.

new memoir evinced new progress, whether it treated of the signs employed in popular script,[1] or showed the identity, by means of the demotic,[2] of the hieroglyphic inscription of Philæ with the decree of Rosetta.[3] The same is true of his Doctor's thesis, in which he gave a résumé of the grammatical system which prevailed in Egypt in the earliest period;[4] of an article in which he showed the identity of a Greek fragment of our library with the demotic papyrus Minutoli 18 of the Berlin Museum,[5] and of the chrestomathy of demotic texts, accurately translated and analyzed, which he attempted to construct.[6] All these publications, so little known to the present generation, belong to the best published in their time. The errors were numerous, it is true, and the works have been severely criticised, but we feel everywhere the profound love of the scholar for his subject, and we must admire the infinite resources of sagacity and patience which he expended to compensate for the real imperfections of his philological education. Had he died at that time, and left nothing else behind him, he would have been reckoned among the masters of Egyptology, in the first class with those who, not content to walk further in the trodden path, have opened new roads.

At first he had neglected the hieroglyphs. Now he ardently began their study; but he had not yet made himself master of them when he undertook, in 1853–54, with the help of the King of Prussia, his first voyage in Egypt. There he met Mariette, and spent several months in the Serapeum studying the recently discovered demotic inscriptions. Next he went to the Said and remained a long time in Thebes. He gave an account of his travels in a notice on the Natron lakes,[7] but especially in his Récits d'Égypte,[8] where he describes, after Champollion, and analyzes the monuments and inscriptions he had seen. The first result of this long excursion in the land of the Pharoahs was that it furnished him with the material necessary for his *Grammaire Démotique*.[9] This book appeared in 1855, and it has endured for forty

[1] Numerorum apud veteres Ægyptios Demoticorum doctrina. Berlin. 1849. 4°.

[2] Die Inschrift von Rosette nach ihrem aegyptisch-demotischen Texte sprachlich und sachlich erklärt, first part of the Sammlung demotischer Urkunden. Berlin. Folio. 1850.

[3] Uebereinstimmung einer hieroglyphischen Inschrift von Philae mit dem griechischen und demotischen Anfangstexte des Dekretes von Rosette. Berlin. 1846. 4°.

[4] De Naturâ et Indolâ linguæ popularis Ægyptiorum. I. De nomine, de dialectis, de litterarum sonis. Berlin. 8°. 1850.

[5] Lettre à M. de Rougé au sujet de la découverte d'un manuscrit bilingue sur papyrus en écriture démotico-égyptienne et en grec cursif de l'an 114 avant notre ère. Berlin. 4°. 1850.

[6] Sammlung demotischer Urkunden. Berlin. 4°. 1850.

[7] Wandrung nach den Natronklöstern in Aegypten. Berlin. 16°. 1855.

[8] Reiseberichte aus Aegypten, über eine in den Jahren 1853–54 unternommene wissenschaftliche Reise nach dem Nilthale. Leipzig. 1855. 8°. Compare Recueil de Monuments. Vols. I–II. Leipzig. 4°. 1863.

[9] Grammaire Démotique, contenant les principes généraux de la langue et de l'écriture populaire des anciens Égyptiensl. Berlin. Folio. 1855.

years. It contains all sorts of inexactitudes, and there is not one page which could remain intact if one thought of publishing a new edition; but, in such a case, we must never judge the value of a work by the errors which are subsequently discovered, because it has served to render generations of scholars better armed than was the author. We must always inquire what the state of science was at the time a work appears, and thus measure the excellence and importance of the services rendered. Demotic had not been read before Brugsch fixed the processes of reading and the syntax; as soon as his grammar appeared it was merely necessary to employ his rules for the decipherment and interpretation of the texts. He understood this fact so well that after 1855 he no longer gave to studies of this sort the time hitherto devoted to them. He translated the tablets of Stobart, which gave him the opportunity to correct the received ideas on the division of the Egyptian year,[1] the bilingual papyri, which Rhind had brought from Thebes,[2] and occasionally new inscriptions, but he left it to others to complete what he had so brilliantly begun. The study of demotic is accompanied by an inconvenience to which the strongest will has more than once yielded. The texts are so small and contain forms so curious that the most careful facsimiles can never render the character. Photography is not always sufficient to reproduce them, and it is necessary to have the originals at hand to understand some passages with certainty. Only a museum curator, who has the papyri at his disposal, can continue with success the study of demotic. Other Egyptologists have always been obliged, by the force of circumstances, to give it up after a certain time, no matter how interested they were or how brilliantly they had begun.

But Brugsch had better work to do than to absorb himself in the interpretation of these unthankful and most fastidious texts. Two subjects had especially occupied him during his stay on the banks of the Nile, the history and the ancient geography of the country. The history still rested on the account written by Champollion-Figeac, after the posthumous note of his brother, for the series of the Univers Pittoresque; while for the geography there were only the accounts of the classical and Coptic epoch, brought together in l'Egypte sous les Pharaons by Champollion-le-Jeune, and in the Mémoires historiques et géographique of Etienne-Quatremère. Harris had just found out the value of the lists engraved on the monuments and had published a few.[3] Brugsch brought back new ones and by comparing them with the old lists deduced the entire series of names under the native Pha-

[1]Nouvelles recherches sur la division de l'année des anciens Égyptiens, suivies d'un mémoire sur les observations planétaires consignées dans quatre tablettes Égyptiennes en écriture démotique. Berlin. 8°. 1855.

[2]A. Henry Rhind's zwei bilingue Papyri, hieratisch und demotisch, übersetzt und herausgegeben. Leipsig. 4°. 1865.

[3]Hieroglyphical Standards representing places in Egypt supposed to be its Nomes and Toparchies, collected by A. C. Harris, M. R. S. L. London. 4°. 1851.

raohs as well as under the Ptolemies. The catalogues of vanquished peoples and of captured cities, which the kings of the conquering dynasties had inscribed on the walls of the temples of Thebes, showed him the state of Syria and Ethiopia at epochs of which there was no previous knowledge. The three volumes Inscriptions Géographiques opened a new world to historians and geographers.[1] The geographers have not, it is true, thought it worth while to explore it, but the Egyptologists have done so. More than twenty years after, Brugsch again took up a part of the subject which he had once treated. His Dictionnaire Géographique, making use of the works of Dümichen, and of the two Rougés, corrected most of the mistakes found in his previous work, but it contains only the names of cities and districts of the valley of the Nile;[2] the Asiatic countries were excluded, as well as the countries on both sides of the Red Sea, and he gave only very short articles, one of which, entitled "La Table ethnographique des Anciens Égyptiens," contains views of remarkable ingenuity.[3] His Histoire d'Égypte, published in French about 1860, embraced the discoveries of Rougé and Mariette;[4] a second French edition in 1875 was only a half success,[5] but the German edition of 1879 crowned the author's reputation.[6] The history begins with the inception of the monarchy and ends with the Macedonian conquest, presenting reign by reign and dynasty by dynasty a brilliant picture of what is known of the destinies of Egypt. The book has been translated into English and it is to-day the classical work on the subject.

But lexicography and grammar, as well as history and geography, engaged the attention of Brugsch. He early recognized the fact, too little understood, that it is no more difficult to prepare three or four books at the same time than it is to write a single memoir. The text studied for a series of mythological facts often contains passages which clear up the sense of an obscure word or render possible the correction of a grammatical rule. If the author does not neglect to note any of the interesting points it nearly always happens that in searching for materials for a historical dissertation he will collect facts for a dictionary article or a grammatical monograph. It is in this way only

[1] Geographische Inschriften altägyptischer Denkmäler, gesammelt während der auf Befehl König Friehrich Wilhelm IV von Preussen unternommen wissenschaftlichen Reise in Aegypten, erläutert und herausgegeben, 3 vols. 4°. Leipzig. 1857–1860.

[2] Dictionnaire Géographique de l'Ancienne Egypte, contenant par ordre alphabétique la nomenclature comparée des noms propres géographiques qui se rencontrent sur les Papyrus. Leipzig. Folio. 1879–1880.

[3] Die altägyptische völkertafel. Berlin. 8°. 1821.

[4] Histoire d'Égypte dès les premiers temps de son existence jusqu' à nos jours. 1ere partie: L'Égypte sous les premiers rois indigènes. Leipzig. 4°. 1859.

[5] Histoire d'Égypte. Iere partie: Introduction, Histoire des Dynasties I–XVII, 2e édit. Leipzig. 8°. 1875.

[6] Geschichte Aegyptens unter den Pharaonen nach den Denkmälern bearbeitet. Leipzig. 8°. 1878.

that we can explain how Brugsch was able to publish so rapidly so many works of importance, and that he found himself able to bring out, six or seven years after, the Inscriptions Géographiques and the Histoire d'Égypte, his Dictionnaire Hiéroglyphique et Démotique. The first four volumes contained all that he had learned during the first twenty years of his life, from 1848 to 1867; the last three added all he had learned during the ten years following, 1868 to 1880.[1] The Grammaire Hiéroglyphique appeared during this interval about 1872. It is not one of his best works; but his dictionary has rendered and still renders a greater service than any other work of any other Egyptologist. The savants of this generation have no idea of the length of time and amount of labor their predecessors required to create the tools which they lacked for their work, and especially those in the field of lexicography. They had to transcribe all the texts on slips, word for word, losing or wasting time in work which can now be devoted to more important researches. Brugsch collected for us a list of words and examples sufficient for the understanding of easy texts. It is only necessary to correct the meanings he proposed to insert the new translations or terms unknown to him, which are but few in comparison with what one had to do before him. Without any doubt errors abounded and serious omissions existed: it will be necessary some day to do this work over again, but the person who undertakes the work will often merely need to copy Brugsch or to modify him slightly in order to produce a permanent work.

Such a variety of production would have been sufficient for the activity of an ordinary man. Brugsch could only satisfy himself by joining to this speculations on the astronomy and religion of ancient Egypt. He had begun with investigations on the constitution of the Egyptian year; later he published his Matériaux pour servir à la reconstruction du Calendrier Égyptien,[2] and still later he devoted two volumes of his Corpus Inscriptionum Aegyptiacarum to new studies of these unfruitful subjects.[3] He had been during his youth a friend of Gladisch, and he was imbued with the more than strange ideas of that scholar. The documents he possessed concerning the mythology and religion of the ancient Egyptians he collected into a large volume, confused and without clearness.[4] This book is already a work of his old age, in which fatigue and discouragement are perceptible. Age had taken away nothing from his physical and intellectual vigor, but life had become hard, and he felt

[1] Hieroglyphisch-Demotisches Wörterbuch, enhaltend in wissenschaftlicher Anordnung und Folge den Wortschatz der heiligen und der Volks-Sprache und Schrift der Alten Aegypter; nebst Erklärung (in deutscher, französcher und arabischer Sprache) der einzelnen Stämme und der davon abgeleiteten Formen. Unter Hinweis auf ihre Verwandschaft mit den entsprechenden Wörtern des Koptischen und der Semitischen Idiome. 7 vols. 4°. Leipzig. 1867–1880.

[2] Leipzig. 1863. 4°.

[3] Thesaurus Inscriptionum Aegyptiacarum: I. Astronomische und Astrologische Inschriften. II. Kalendarische Inschriften. Leipzig. 4°. 1863–1884.

[4] Religion und Mythologie der Alten Aegypter. Leipzig. 8°. 1888.

keenly the want of a permanent position with a sufficient income for his needs and for a style of living in keeping with his great reputation. He began to write for publishers; and the works he published, his World of Tombs,[1] his Voyages in Persia and to the turquoise mines,[2] or to the oasis of Khargeh,[3] his Thesaurus Inscriptionum Aegyptiacarum, his manual of Egyptology,[4] his Egyptian Commentary on the Bible,[5] show traces of haste. The bitterness and the resentment of a blighted life appeared in his speech and in his writings. Often when he came back from a visit to his beloved Egypt he recovered his joyousness and prepared a work written in the best spirit of his early days. Such is his essay on the so-called famine stèle, discovered by Wilbour.[6] This pleasant frame of mind would soon be obliterated in Europe, and the reading of his Recollections shows that toward the end he was not always just to the men of the new generation. He died more admired than loved by all those who owe so much to him, although he never quite secured the respect and the sympathy inspired by his friend Mariette in all who met him.

I do not allow myself to pass judgment on his work, for I profited too greatly by him not to award him a profound recognition. Like all Egyptologists, I have myself corrected hundreds of his errors or incorrect opinions. I have been troubled by the disorder which reigned in the composition of his works and by the ignorance he affected toward the works of others; but how many qualities did he not have to fully compensate these defects. Three men have contributed more than all others to make Egyptology what it is. Champollion founded it; E. de Rougé has created for it a method; Brugsch forged the tools which for a long time have served and will continue to serve the science of Egyptology.

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[1] Die Aegyptische Gräberwelt. Leipzig. 8°. 1868.

[2] Wanderung nach den Türkis-Minen und der Sinai-Halbinsel. Leipzig. 8. 1866.

[3] Reise nach den grossen Oase El-Khargeh in der libyschen Wüste, Beschreibung ihrer Denkmäler und wissenschaftliche Untersuchungen über das Vokommen der Oasen in den altägyptischen Inschriften auf Stein und Papyrus. Leipzig. 4. 1878.

[4] Die Aegyptologie, Abriss der Entzifferungen und Forschungen auf dem Gebiete der ägyptischen Schrift, Sprache und Alterthumskunde. Leipzig. 8°. 1891.

[5] Steinschrift und Bibelwort, 2d ed. Berlin. 8°. 1891.

[6] Die biblischen sieben Jahre der Hungersnoth nach dem Wortlaut einer altägyptischen Felsen-Inschrift. Leipzig. 8°. 1891.

A BIOGRAPHICAL SKETCH OF JOHN ADAM RYDER.[1]

By HARRISON ALLEN, M. D.

I.

JOHN ADAM RYDER,[2] the first child of his parents, was born February 29, 1852, near Loudon, Franklin County, Pa. His parents are Benjamin Longenecker Ryder and Anna Frick Ryder. On his father's side he was descended from Michael Ryder, who was one of three sons whose father came from England and settled near Cape Cod, Massachusetts. Michael Ryder removed from Massachusetts to Pennsylvania, where his descendants have since lived. His paternal grandmother, Elizabeth Longenecker, the wife of Adam Ryder, was of German origin. She was born in Lancaster County, Pa.

Anna Frick Ryder, the mother of John Ryder, was born in Maryland. She is in part of Swiss descent. The maternal grardmother, Anna Kelso, was of Scotch origin. Her great-grandfather was William, Earl of Kelso. At the time of the persecution of the Presbyterians in Scotland during the reign of Charles II, the Earl of Kelso, together with his wife, infant son, and brother James, were compelled to leave Scotland. They sought refuge in Ireland, where James Kelso was captured, taken to London, and executed. The estates were confiscated. A grandson of William Kelso, above referred to, came to America.

[1] Printed in Proceedings of the Academy of Natural Sciences of Philadelphia, April, 1896, pp. 222–239. Bibliography not reprintdd.

[2] In the preparation of this sketch the list of questions prepared by Mr. Galton in his monograph on "Men of Science" was sent to the family of Dr. Ryder, and the details in all respects are based upon the answers received. The expressions of opinion of the speakers at a meeting held at the Academy's Hall, April 10, 1895, have been frequently quoted. The words "Memorial Pamphlet," when following a quotation refers to a brochure entitled "In Memoriam," which comprises addresses delivered at that meeting in the following order: Dr. Harrison Allen, Dr. Bashford Dean, Prof. Horace Jayne, Prof. E. D. Cope, Mr. H. F. Moore, and Prof. W. P. Wilson. The brochure was printed for private distribution by a few admirers of Dr. Ryder in the fall of 1895. The writer desires to express his acknowledgments to many of Dr. Ryder's associates for information, especially to Rev. Jesse Y. Burk, secretary of board of trustees, University of Pennsylvania, Mr. W. C. Seal, of Philadelphia, Prof. J. S. Kingsley, of Tufts College, Massachusetts, Mr. Edward Brooks, superintendent of the public schools of Pennsylvania, and Mr. Herbert A. Gill, secretary of the United States Fish Commission.

It will be thus seen that Dr. Ryder was twice removed from ancestors who combined English, Scotch, German, and Swiss traits.

Dr. Ryder's father was by training a farmer. He became interested in horticulture, and at one time conducted a large nursery. His talents for invention are of an exceptional order. He has improved mechanical devices for preserving and curing fruits, vegetable and animal products, and has become widely known in connection with their manufacture and introduction.

Dr. Ryder's inventive ability can be traced in great measure to his father and remotely to the Longenecker branch of the family. His mother, however, possesses inventive skill in no mean degree. Ryder had no taste for music. In this respect he resembled his mother, since the taste was well developed in the father. He had a natural facility for drawing, although he never cultivated it beyond what was necessary for the illustration of his papers and for the class room. This talent also is traceable to his father. His taste for natural history is a direct inheritance from his mother. While Dr. Ryder never became much interested in medicine, many phases of his researches are so closely allied to this science that he may be said to have inherited the taste from his father, who, although never having studied medicine systematically, had that turn of mind which is constantly tending to contemplate the nature of disease. A paternal aunt of Dr. Ryder studied medicine. She was never graduated. Her medical opinion was frequently sought for and valued in the community where she lived. She was also of an inventive turn of mind.

Dr. Ryder early exhibited a taste for natural history. When 3 years old he was constantly bringing into the house brightly colored stones, insects, and other natural objects. At 8 years he knew the botanical names of all the plants in his father's nursery. While very young he was noted for a habit which distinguished him throughout life, namely, of always having his mind occupied with something apart from the duties in hand. Thus, while helping his father at pruning or grafting, he would recite aloud passages from a favorite author, a copy of which would be found in his pocket. On one occasion, his father hearing hearty laughter, asked him the cause of his mirth. The boy replied that he wondered how Diogenes felt living in such a small place as a tub, and what fun he must have had searching for the honest man.

Every farmer in those days kept a few swarms of bees. While Mr. Ryder was not a professional apiculturist, he knew in common with his neighbors a good deal about the raising of bees. Ryder developed an interest and without being specially instructed became proficient in the care of bees, and throughout life often reverted to their habits for many points in the economy of insects.

At 3 years of age he began to receive instruction from his maternal grandmother, from whom he early mastered the rudiments of German. He attributed his subsequent fluency in German (for he could speak it

like a native) to this early impression. A little book entitled "Biblische Naturgeschichte für Kinder" bears his name on the cover with the date of 1860.

Ryder spent the life usual to a country boy. He possessed great energy of body and was fond of walking, rarely, if ever, using a horse to ride, although the stable was at his command. He attended the country school from the age of 6 or 7 until his fifteenth year, when he ran away. Soon afterwards he was sent to the academy and then to the normal school at Millersville, from which he also ran away, and did not return home, but lived the life of a tramp for some days before he was detected. He was severely punished for both these escapades. It appears that Ryder was always very sensitive and never associated with boys of his age in the sports customary to youth, but wandered about alone through the woods and meadows, collecting insects and plants. He sooned earned the nickname of "Crazy John." In the end his father prudently interviewed the principal of the academy and made special arrangements which enabled Ryder to live on more agreeable terms. But he was unhappy under restraint. Class work was distasteful to him and discipline of any kind resented. In order to secure his obedience it was sometimes necessary to give him directions adverse to those which it was intended for him to obey. Preferring to study in his own way, he spent the greater portion of his time in the library of one of the local literary societies. He read every book it contained. He was greatly influenced by Horace Mann's "Thoughts for a Young Man,"[1] a copy of which he procured. In 1875, in writing to his brother, he said: "Be careful of this book; five dollars would not buy it if I were unable to get another." In 1868, when in his sixteenth year, he wrote home asking for a microscope, books on natural history, chemical apparatus, etc. His restless spirit caused him to drop out of the school for good after a few months.

He taught school in the neighborhood of Loudon and afterward in the high school of the county for three years. He was quite successful and was much esteemed by all who were brought in contact with him.

We now find Ryder in his twenty-second year with the best equipment it was possible to secure for him in a rural district. His tastes were defined, and he at once made up his mind to devote himself to the study of science. This decision was quickened by the failure of his father in business, so that Ryder was thrown entirely upon his own resources. Of a proud disposition, he refused all assistance from his relatives, and learning that the Jessup Fund of the Academy of Natural Sciences of Philadelphia afforded assistance to young men who were desirous of devoting themselves to the study of natural history, he came to Philadelphia in the spring of 1874, and appealed to Mr. Thomas

[1] A few Thoughts for a Young Man: a Lecture delivered before the Boston Mercantile Library Association on its 29th Anniversary. By Horace Mann. Boston: Ticknor, Reed and Fields, 1850.

Meehan, an old friend of his father, for advice. Mr. Meehan states that Ryder visited him at his residence in Germantown. His funds were low, and to save money he had walked the entire distance, 12 miles, from Philadelphia. Mr. Meehan was interested in Ryder, who was, however, urged not to attempt to live on the small amount of $5 a week permitted by the fund. But Ryder was not to be deterred. He felt confident that he could in some way manage, and accordingly, armed with a letter of introduction, he visited the academy and made formal application. This was, at first, unsuccessful, but in the latter part of the year he was duly appointed. He remained in the academy as a beneficiary of the fund for six years.

Little is known of his private life during the greater part of this time. In 1879, Mr. J. S. Kingsley, now Professor of Biology in Tuft's College, Massachusetts, was his associate, and through him it is ascertained that Ryder lived on the top floor of No. 1113 Chestnut street. His chamber and laboratory were one. Upper rooms in business blocks were then cheap, and food at moderate prices, offered for the use of employees of newspaper offices in the neighborhood, could be obtained day and night. The markets and restaurants of Philadelphia furnish plain, wholesome food at rates which compare favorably with those in any American city. Meals at 15 cents each are important factors in solving a problem of living on 70 cents a day. It was the custom of the proprietor of the restaurant frequented by Ryder to put aside for him the oyster shells, which, after each meal, were inspected for organisms. In this way he discovered the sponge *Camaraphysema*. Doubtless the work on the habits and food of the oyster, on which Ryder's fame in a measure rests, began in these desultory studies.

It was a time of formative plans. Among these may be recalled—an educational scheme by which the teachers in the public schools were to be prepared for imparting the elements of biology to their pupils; a course of popular lectures at the Wagner Institute; and a series of papers on natural history for a Philadelphia paper. None of these came to anything.

Such a life in a region of stores and warehouses is well enough during the week. The days and nights are separated by the changes in light—but not by changes in habit. But on Sunday the business part of a city is but little better than a desert. Ryder was in the habit of spending this day, when the season favored his so doing, in the suburban districts, or in Fairmount Park. It was on such excursions he discovered *Scolopendrella* and *Eurypauropus*.

The previous education of Ryder was one inadequately qualifying him for the career of a naturalist. This, indeed, is not less than that required to equip a student for any intellectual career whatsoever. How immense the labor when one is compelled to equip himself! The naturalist must be a linguist (for there is scarcely a modern European language which may not possess a treasure for his needs); he is all the

better for being a draughtsman; he should command a good literary style; he should be a mathematician and physicist. Ryder, in these preparatory years, attempted all these things but the last. His endeavors to acquire new languages and a good literary style were unending. One of his favorite pastimes was to read an essay of Addison twice and then write out the essay from memory. He would then compare his sketch with the original. His tastes in art were not formed, and he rarely alluded to the subjects embraced among the humanities.

Mr. W. P. Seal, the well-known aquarium expert, was of great value to Ryder at this time in bringing him all the unusual specimens he detected while making collections of fresh water fishes and plants in the neighborhood of Philadelphia. At the end of his service in the Academy, Ryder had contributed thirty-one papers, most of which were based upon studies made in the museum or on low forms of life.

In 1880, the National Government was desirous of having investigations prosecuted in behalf of the United States Fish Commission on the life history of the American food fishes and other aquatic animals, especially their embryology and growth, the character of their food in the early as well as the later stages of life. In the judgment of Professor Baird, who was at that time Commissioner, no one in the country possessed the qualifications to meet the provisions of such investigations in so high a degree as Dr. Ryder.

He was at once invited to undertake the work, which not only gave him an opportunity of systematizing his studies (these were already embracing the higher problems in biology), but had the advantage of placing him in a better paid position.

It is true that up to this date Ryder had given no special attention to fishes, but he had obtained a general knowledge of the subject at the academy; his inherited talent for invention lent itself readily to the details of field work, while his acquaintance with the lower forms of aquatic life fitted him for the study of the food of fishes, the study of their young stages, their parasites, etc.[1]

Dr. Ryder always referred to this period with interest. His first detail was to the field, but, in 1882, Professor Baird transferred him to the National Museum, occasionally only assigning him to field work. He was extraordinarily active during the six years he remained on the Commission. He contributed twenty-nine papers on the oyster and oyster culture, and fifty papers on the development of fishes, their food material and methods of development. All his contributions were carefully prepared and showed extensive knowledge of the subjects treated. He discovered, in 1888, a byssus in a young stage of

[1](1) The following papers, prior to 1880, related to Dr. Ryder's contribution to ichthyology: "On the origin of bilateral symmetry and the numerous segments of the soft rays of fishes;" "Phosphorescence of very young fishes;" "The Psorosperms found in *Aphredoderus sayanus*."

the long clam *Mya arenaria*. Professor Baird, in commenting on this discovery in his report for that year, believed "it to be of economic importance since the young individuals now can be freely handled and transported." Mr. Bashford Dean remarks: "I have heard it said that Dr. Ryder had, in his scientific work, grown up with the Commission; it might, I think, be said even as justly that the Commission had, in a measure, grown up with him."[1] His personality and methods had stamped themselves upon every officer of the Commission to which he had been originally attached as an expert. He "merited the confidence and esteem of everyone, from the Commissioner to the humblest attendant."

On the occasion of his resignation, 1886, Professor Baird expressed himself in a personal letter in these words: "In view of the many years of your connection with the Fish Commission and the valuable services which you have rendered by the exercise of your professional skill and ability, I accept your resignation with very great regret." His work, however, on the commission did not at once cease. He was employed in May and June, 1888, to investigate the sturgeon fisheries in the Delaware River.[2] During the remainder of the summer of the same year he had charge of the station at Woods Hole.

His interest in the study of cetacea began while on the commission. Although his work on this subject was never extensive, perhaps no other group of observations better illustrate the higher characteristics of his mind.

In 1886 it was determined by the authorities of the University of Pennsylvania, at the suggestion of Prof. Horace Jayne, to found a chair of Comparative Histology and Embryology. As stated by Professor Jayne, "It was seen that a course was needed which would give students a thorough knowledge of comparative microscopic anatomy, together with the development of the tissues and of the different kinds of animal forms."[1] The chair was offered to Dr. Ryder and accepted, though "he hesitated at first," to again quote Professor Jayne, "because he mistrusted his power to teach and handle large classes of students, a mistrust which was never shared by his friends." In many respects the change from the duties of a biological expert on the Fish Commission to those of a professorial position was beneficial. He was now enabled to systematize his time and permitted to extend the range of his inquiries. By renewal of associations at the Academy of Natural Sciences he was assisted also in keeping thoroughly in touch with the progress of his favorite science.

In illustration of the zeal with which he prepared himself for his new duties the following extract is taken from a letter written to Mr. Seal, from Chambersburg: "I am embracing an opportunity for the collection

[1] Memorial Pamphlet.

[2] Report of Fish Commission, Bulletin, 1888, page 231.

of embryos of warm-blooded vertebrates, which I have never enjoyed until this season; and unless one can give his whole time to the work of opening hundreds of females with great care and have the means and time to preserve the material obtained it is but very little use to bother with the subject. I have eviscerated about five hundred rats, mice, field mice, moles, bats, and muskrats. I have a fine lot of embryos of all stages nicely preserved. Besides this I have obtained 250 sparrow's eggs in all stages of incubation, which I have also put in good condition."

After an experience of nine years, terminating only in his death, it can be said of him that all the expectations raised at the time of his appointment were more than realized. He proved himself to be a diligent teacher and an esteemed colleague. As matters appear to be arranged for men of Ryder's attainments, a university position is the best available. Speaking for the personal side of his career, it may be said of him, as I am sure he might have said for himself, that to receive the respectful admiration and affection of pupils and to influence for good the mental development of youth is for any man a sufficient reward. A former pupil, Mr. H. F. Moore, says of him: "What he may have lacked in some of the usual attributes of a successful teacher was more than compensated for by his keen sympathy, his painstaking care, and his skill with crayon and pencil. If he had found a point of interest in his work he usually invited us to enter, and would unfold to us his hopes and aspirations with the enthusiasm and simplicity of youth." Yet, after all is said, one must agree with his friend, Mr. W. V. McKean, that "Ryder was essentially the kind of investigator that it would have been a public benefit to have established in an amply endowed university chair, so that he might be entirely free to pursue his researches unhindered by any mere task work."

Dr. Ryder enjoyed perfect health until 1882, when he contracted malaria while engaged in some researches in connection with his work on the Fish Commission, at Ridge, Md. He suffered from a recurrence in 1888, while residing in Philadelphia. About this time dyspepsia announced itself. He suffered greatly and became much emaciated. In the summer of 1890 he visited Europe, but returned scarcely at all improved. He had an attack of the prevailing influenza in 1894, and from this time more serious and obscure impairment of the general health ensued. He died March 26, 1895, after an acute illness of a few days, aged 43 years.

Dr. Ryder's death was unexpected, and expressions of regret were universal. The daily papers published detailed accounts of his life and services. Immediately after the death the board of trustees of the university held a meeting, at which Dr. S. Weir Mitchell made a feeling announcement. The board then passed the following resolution:

The trustees of the University of Pennsylvania deplore the loss sustained by it in the death of John A. Ryder, Ph. D., professor of comparative histology and embryology. Called to that chair in 1886, he

quitted for it a congenial field of labor under the United States Fish Commission, in which he had rendered great service to the Government and acquired for himself a world-wide reputation. Thenceforth he devoted himself equally, and with a fidelity and effectiveness that ended only with his life, to the work of a teacher and that of an investigator. His characteristic traits were modesty, unselfishness, and sincerity in the search for truth. To these were added a rare talent for investigation, strong intellectual capacity, and unremitting industry; and these inured not only to the benefit of the school in which he taught, but to the distinct advancement, both in theory and in application to the science of biology, to which his life was consecrated.

The funeral services were conducted by Prof. George F. Fullerton, vice-provost, and the Rev. Dr. H. C. McCook. His body was cremated.

A memorial meeting, held in the hall of the Academy ot Natural Sciences of Philadelphia, April 10, was participated in by members of the faculty of the University of Pennsylvania, representatives of the American Philosophical Society, the United States Fish Commission, and the Academy.[1]

Dr. Ryder was elected a member of the Academy of Natural Sciences of Philadelphia January 29, 1878, and of the biological section of that body November 15, 1886. He was director of the section from 1886 to 1888. He was elected a member of the American Philosophical Society December 17, 1886. The University of Pennsylvania conferred upon him the degree of doctor of philosophy, 1886. He was also a member of the following societies: The Zoological Society of Philadelphia (life member), the American Morphological Society, the American Society of Naturalists, the American Association for the Advancement of Science, the Association of American Anatomists, and the Historical Society of Pennsylvania.

II.

Dr. Ryder was a man of restless mental activity. Plan after plan was discussed in his early letters. No defense was offered for this eagerness of spirit. On the contrary, he says in one of his outbursts. "I see more worlds ahead of me to conquer, so that I have little time to attend to number one, that often restive and troublesome person who is always reaching for toys he ought not to have, greatly to the disadvantage of more serious matters." Circumstances annulled most of his numerous enterprises, but the ideas were, without exception, admirable, and some of them were afterwards realized by others. In In 1879 he proposed to establish in Philadelphia, in conjunction with Mr. W. C. Seal, a depot of material for biological laboratories and class-room demonstrations. It was intended that Mr. Seal would collect and preserve the specimens which Dr. Ryder would undertake to identify and to furnish all other information. It was designed to embrace marine and fresh water as well as terrestrial forms. In association with his friend, Mr. J. S. Kingsley, he at one time thought of

[1] See note on page 673.

writing a book on the infusoria, a work that yet remains a desideratum. Dr. Ryder had a ready knowledge of the group. In later years he constantly reverted to it for illustration in his studies of the movements of protoplasm. A third undertaking on the embryology of fishes was proposed. It never went further than the title-page. In 1887 he seriously contemplated a text-book on general embryology. It was to be "copiously illustrated and to set forth the principles from new points of view." To this task he intended devoting two or three years. In 1893 he published, under the auspices of the University of Pennsylvania, a pamphlet entitled "The Synthetical Museum of Comparative Anatomy as the Basis for a Comprehensive System of Research."

It is a remarkable fact that Dr. Ryder, in his active and versatile career, never wrote an extended memoir. Everything he prepared for the press was the direct outcome of the practical tasks upon which he was officially engaged.

His work in zoology[1] was not large. Reference to the bibliography shows that twelve papers may be so classified. He once said: "The species makers are caviare to me." But he himself did not escape the fate of most biologists in the making of species.

I have given my impressions of his disinclination to study species elsewhere:[2]

> In competent hands the elucidation of species is not, as it has opprobriously been said to be, a dullard's task of taking an inventory of nature, but the study of the ultimate forms which those organisms assume which breed true. The shifting of color schemes, the exhibition of the effects of food and climate on size in whole or in parts, and of other causes by which minute differentiations are started and maintained, are of unending interest and worthy of the best powers of the naturalist. If Ryder had been more closely identified than he was with the careers of the great academicians who had preceded him it would in no whit have detracted from the value of his philosophical labors. One can not but regret, if for no other reason than for his health's sake, that he discontinued those fruitful excursions to our woods, ponds, and rivers, by which he contributed so notably to our micro-fauna.

While Dr. Ryder did not identify himself with zoology, his reputation may be said to rest in great part upon his labors on the morphology of the early stages of the development of fishes. This work, for the most part, represents that accomplished by him as an expert on the Fish Commission. His interest in the subject of the nature of species was, however, a deep-seated one, and he was constantly reviewing masses of data which he had accumulated in attempting to explain the tenets

[1] Dr. Ryder made a few observations in physiological botany. Early in his career, viz, 1877, he noted the disposition of the tendrils of *Cocculus indicus* to twine. (Proc. A. N. S., 1877, 3.) In 1879 he observed the honey glands of the leaves of *Catalpa*, and the habits of bees respecting them. (Proc. A. N. S., 1879, 6; Pastime, 1881, II, 8; Am. Nat., 1878, 4.)

[2] Memorial pamphlet.

of evolution. That these attempts should have been largely in the direction of dynamics was to be expected, since he was enabled to apply to the problems his talent for mechanics and invention. He also had at hand the conclusions of many contemporaries who were with him eagerly seeking for a hypothesis of evolution not embraced in that of natural selection.

As early as 1874 he wrote :

I think I have discovered a law which offers a way to the solution of the variations of forms in animal life. This law I propose to call the law of the dynamics of phylogeny. In reading over Herbert Spencer's brilliant essay on the circulation of sap in plants and the formation of wood, I saw the solution of the problem. Here is field enough for a Darwin. I almost shrink from the task when I consider its magnitude. Cleavage of muscular fiber; the processes of bone; the arrangement of the bony layers; the change of form and length and of position of bony processes; their relations as a whole; their relations to the muscles; their form, arrangements, etc., all proclaim a common law, while every abnormality, injury, reparative expedient, still further strengthens it in my mind, and is the only thing that will demonstrate to the world the truths of the doctrines of unity of law and universal evolution. It completes Darwin's work on a grander scale than Darwin ever dreamed of. It still further declares that there is one eternal ever-active cause, operating in lines of constant and mathematical precision. If Dr. Haughton, of Cambridge, can demonstrate the mathematics of the bones and muscles, surely someone else can study the dynamics that creates them.

His first work in speculative biology was an attempt to explain by such reasoning a law of reduction of digits in the mammalia.[1] In the same year he endeavored to establish a dynamical theory to account for the modifications in the forms of tooth structure and to correlate this structure with the shapes of the lower jaw and other parts of the skull. In the following year he discussed the mechanical genesis, degeneration, and coalescence of vertebral centra in a gigantic extinct armadillo.

He developed a theory on the origin of the amnion in 1886, and his explanation of the different types of placentæ in 1887. In 1889 he defended the thesis "that the segmentation of the soft rays of the fins of fishes are simply fractures due to flexures, and that on the caudal fin they possess probably the same direction as the intermyomeric fissures."[2] Ryder's bibliography contains fourteen titles of papers which illustrate similar lines of reasoning.

In the same year we have evidence of additions to his methods, for, while keeping to the lines already indicated, he added others of a different character, and sustained by broadly contrasted methods of expression. Allusion is made especially to his studies of the contractility of protoplasm, which is first mentioned in his paper on "The fore and

[1] Law of Digital Reduction, Proc. A. N. S., 1877.

[2] E. D. Cope, Memorial pamphlet.

aft poles, the axial differentiation, and a possible anterior sensory apparatus of *Volvox minor*," and in his paper on "The origin and meaning of sex." These papers began a series which (included in the bibliography under numbers 174, 186, 190, and 191) dealt not so much with problems in dynamics as with the old vital doctrines, or, as would be expressed in modern phrase, metabolism. "The origin and meaning of sex" appeared in the Biological Bulletin, University of Pennsylvania, 1889. Extensions of opinion were printed in the Proceedings of the Academy, 1889, and in the American Naturalist, 1889, 501. He held that overnutrition led to all forms of sexual reproduction; that the male and female elements are contrasted in their tendency to undergo segmentation—the female element having lost the power to undergo such segmentation spontaneously (excepting in parthenogenesis)—while the male element is accompanied by an increase of segmental power. * * * "Sex probably arose simultaneously and independently in both female and male as soon as certain cells of coherent groups became overnourished and incapable of further segmentation unless brought into contact and fused with the minute male element, or one which is the product of an increase of segmentational power which is transferred to the female element in the act of fertilization." Important applications were made of the hypothesis to the study of variation, the evolution of sexual characters, and, as the author believed, a consistent and simple theory of inheritance which is in harmony with all the facts of reproduction. At this time he was in a state bordering on exaltation. "I sat up late last night after the whole thing flashed across my mind in an instant," he writes, "and did not sleep for two hours after I went to bed because by brain was going like a dynamo, thinking out detail after detail of my hypothesis. * * * Wolfe and Schwann mark two eras in the history of hypothesis. I shall mark a third if I live to complete the sketch of the vast hypothesis. * * * My disappointments vanish into the uttermost inane when I think of what it has been possible for me to achieve."

After such strong evidence of his belief in the value of this theory, it is hard to understand how he practically dropped the subject. Subsequent to the dates above given, I have come across no reference to it, nor is any mention made of the matter in the estimates of his work that have appeared since his death.

It is impossible to understand Ryder's attitude toward evolution without regarding his disbelief in the "cult" usually known as Weismannism, which embraces the opinions that acquired characters can not be transmitted, and that a portion of each organism is carried unchanged from parent to offspring. He said, in his paper on sex, "The hypothesis which assumes that the germ plasma is precociously set aside in order to render it unmiscible with the somatic plasma, and therefore immortal, is based upon a fundamental error of interpretation of the facts of morphology." In another place, an address entitled

"Dynamics in evolution," 1893, he said: "Experimental investigations in embryology will make no solid progress until the mischievous influence of such speculations have been eradicated from the minds of the present generation." These opinions remained unmodified to the day of his death. Perhaps the best expression of his views can be found in a lecture delivered at Woods Hole, 1894, and a second lecture, entitled "A dynamical hypothesis of inheritance."

The last phase of his scientific life is the most instructive, namely, that relating to the application of geometery and the differential calculus to the study of organic forms. The idea that anatomy and mathematics can be of mutual assistance generally comes to savants too late for practical use. Against the example of Helmholtz we cite many failures. Mathematics came to John Goodsir too late for anatomy, and anatomy to Fechner too late for mathematics. When Ryder saw the necessity of preparing himself in these sciences (for his early training had excluded them), he set to work to supply the defect with characteristic energy. He studied geometery and the calculus in spare hours. He became enthusiastic for them. He declared geometry to be the noblest of the sciences. He read the writings of Lord Kelvin carefully; his admiration for them was unbounded. At the time of Ryder's death two works lay on the bed: one was a text-book on the differential calculus, the other a volume of Lord Kelvin's works.

It is difficult to fix a time when the mathematical explanation of the mechanics of evolution occurred to him. We have seen that he was influenced by Haughton as early as 1874. If we can draw an inference from the reading of the paper entitled "The fore and aft poles of *Volvox minor*," previously quoted, and, again, the essay "The polar differentiation of *Volvox minor*" and "Specialization of possible anterior sense organs" (No. 174, Bibliography), the idea apparently suggested itself by studies in the early Academy days on the infusoria, and later on the development of simple organisms. The same conception occurs in his papers on "Energy in biological evolution;" "Of the representation of the relative intensity of the conflict between organisms;" "Energy as a factor in organic evolution;" "Mechanical genesis of the form of the fowl's egg;" "The adaptive forms and vortex motions of the substance of the red blood corpuscles of vertebrates;" "The correlation of the volumes and surfaces of organisms."[1] One of the last demonstrations he made was at a meeting of the Bibliographical Club of the University of Pennsylvania, when he exhibited contractile films of gelatin in illustration of the mechanical conditions underlying the problem of the arrangement of the convolutions of the brain.

In January, 1890, he writes:

It is my hope to reduce the doctrine of evolution into a simple realization of Newtonian principles. The three great Newtonian laws of motion

[1] See Bibliography, Nos. 182, 184, 186, 187, 189, and especially Nos. 190, 191, 192, 195, 199, 200, 204, 205, 206, and 207. Proc. Acad. Nat. Sci., Phil., April, 1896.

are at the bottom of the whole matter. Some day I shall be able to tell a great deal that I have kept to myself in order to test its truth. * * * I am engaged—and will be hereafter almost entirely—in determining the factors and processes which have effected the evolution and divergence of species. * * * I have at last worked out a new theory of inheritance which must ultimately replace those of Weismann and Darwin, or at least furnish the foundation by which the data and phenomena of variation and inheritance can be coordinated with the great universal principle of the doctrine of the conservation of energy. The speculations of Darwin, Haeckel, Weismann, Brooks, De Bries, Strassburger, and Nageli looking to a theory of inheritance are irreconcilable with the fundamental postulates of physical science, and must be abandoned. This also renders the conflict between the hypothesis of Darwin and those of Lamarck one of primary importance, and sharply defines the line of battle between the thinkers who range themselves under the banner of one or the other of these prophets of transformism.

While it is impossible to say what Dr. Ryder would have accomplished in his attempt to use mathematics as a medium of expression of biological problems, this much can be said, not only for him, but for all others similarly placed, that a course of training in geometry and the higher mathematics should be a part of the equipment of the student in biology. It does, indeed, seem pitiable that, ascending the heights of knowledge, he finds, as he nears the top, that the key which he believes can alone open the temple erected there has been left behind.

III.

Dr. Ryder was 5 feet 11 inches high, of a slender, slightly stooping figure. While spare, he had a robust physique. He was of nervous temperament. His complexion was light—the hair flaxen. He was plain—almost careless—in his dress. He had a habit of sitting cross-legged and swinging one foot when deeply engaged in thought or study. He was of a genial disposition and enjoyed gatherings with his students after class hours, or discussions with his colleagues and friends at the academy and other places. His learning was great, especially in contemporary literature, and nothing appeared to give him so much pleasure as talking of the work of his colaborers; but he disliked what are called "social functions," and toward the latter part of his life was rarely present at them. From the beginning of his scientific career to his later years he did not require much sleep, taking about six hours daily, though his habits in this respect were never regular. He had great energy of mind, and power of accomplishing a large amount of brain work. His memory was remarkably retentive—he never forgot anything he once heard or read. In addition to his early attainment of German, he read, for scientific purposes, French, Italian, Spanish, Dutch, Danish, Swedish, and Russian.

His sense of duty was highly developed. He believed that the power of the will over action was practically without limit. Yet the motive for the exercise of the will must be from within. Hence can be explained

his apparent obstinacy of disposition as a child, his aversion to class work at school, and his independence of convention, both as to thought and action, in mature life.

Some time prior to his appointment on the Fish Commission, Mr. W. V. McKean invited him to write articles on natural history for the Public Ledger. But Ryder could not overcome a distrust that his essays would be too technical for popular favor. That he should have declined an offer apparently so advantageous to himself at a time when he needed money is an evidence of the rigid scrutiny to which he subjected all his actions. None but his most intimate friends knew of the costs he often paid to maintain his freedom of mental action. They were met without a murmur. But in their payment he doubtless drew largely on that vital energy without which long life is impossible. His dearest friend said of him: "His self-sacrificing devotion cost him his life."

But, under the stern repression lay a childlike, affectionate nature. He was not happy unless he had one or more of his family with him; he was continually writing to the absent ones. His domestic letters contain full accounts of how he lived, whom he met, and of his enthusiasm for his discoveries. Those who knew him only as a scientist had but little conception of the spirit that actuated him. His work was not a series of merely intellectual achievements, but back of it all lay the feeling that he was bringing something bright and interesting from the outside world to adorn the home.

His affection for kin extended to his friends. His relations with Professor Baird were almost those of son. His anxiety and distress at Professor Baird's last illness found expression in all the letters he wrote at that time. As is common with such natures, his sense of justice was keen, though no instance can be shown in which his indignanation was not excited by the general sense of wrong implied in the situation rather than by any personal feeling.

Dr. Ryder's religious training was that of the strict orthodox Christian faith as expressed in the teachings of the Mennonites. His paternal grandmother, who directed his education, was a woman of deep piety. For the faith of his parents he always entertained the profoundest respect, and at least toward the latter part of his life was inclined to return to it. At the age of 18 he studied the Bible closely; and, ever afterwards, no matter how limited his traveling effects, a copy of the New Testament was always among them. Though, as shown by his letters, he departed from the tenets of his early education, one can not doubt that he retained all the force of a severe mental and moral discipline that such teaching implies. He was faithful in friendship, singularly frank and sincere in disposition, and disliked violent language, dispute, or criticism. He was always severe to himself, but sacrificing in spirit to those whom he loved.

While a Jessup Fund student he became a devoted listener to the Rev. Mr. Mangasarian, an Armenian preacher, who, at that time, held

a pulpit in a Presbyterian church in Philadelphia, but who afterwards became a leader in an independent organization allied to the Society of Ethical Culture. In speaking of Mangasarian in one of his letters, Dr. Ryder uses the following language: "He has all the charm of the finished orator, combined with rationalism and advanced evolution." Ryder greatly admired Emerson. He spoke of him as "the sanest man of the nineteenth century." In writing to a friend who was in mental distress, he advised him to read Emerson. He carried his admiration even to matters of scientific import. In his last paper he quotes from this writer the saying: "To a sound judgment the most abstract truth is the most practical." He was much influenced by the teachings of the Stoics. "I would strongly advise you," said he to a friend, "to get hold of the thoughts of Marcus Aurelius, when you are most provoked or vexed in spirit, and take their lessons to heart. Epictetus will do equally well, only I think Marcus is calculated to humble and content a man." His letters contain many expressions of trust in an Infinite Beneficence, and he would have agreed with Epictetus as to "Whither dost thou tend after death, that is to nothing dreadful, but to a place from whence thou camest, to things friendly and akin to thee."

We admire Ryder not so much for what he accomplished as for the indomitable spirit that actuated him. With imperfect equipment, with engrossing occupation, and—for much of his intellectual life, at least—with impaired health, he attempted the solution of the most difficult problems. It is not for us to consider in what degree he succeeded. Had Bacon, Franklin, or Darwin died at 43, or had their days been absorbed, as his had been, in cares and the routine of task work, how much less would have been their achievements! It is enough for us to know that we are studying in Ryder's life phenomena of a mind of the first order, and that we have lost by his death one of the brightest of the group of workers to which he belonged.

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